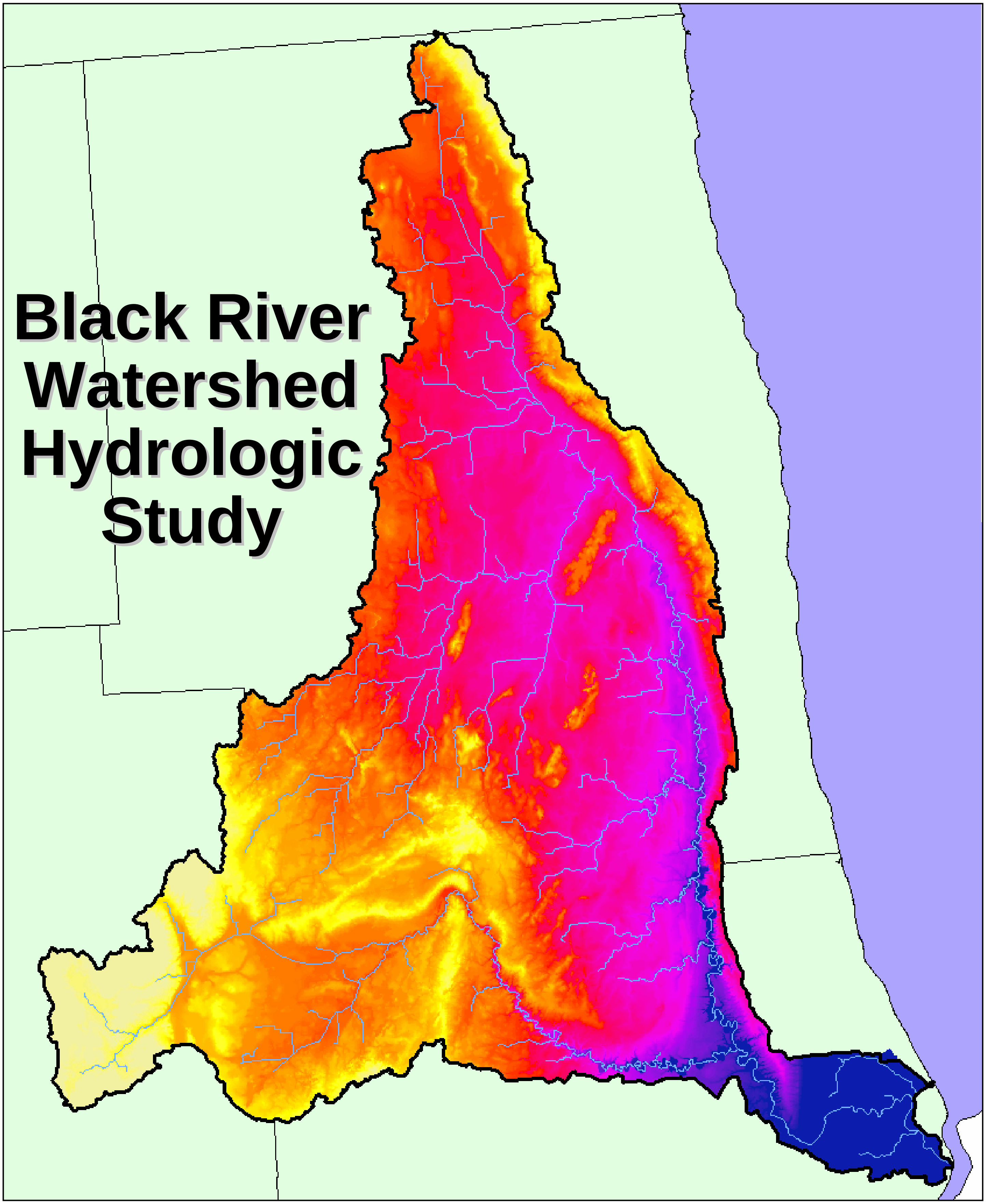
Black River Watershed Hydrologic Study



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This Nonpoint Source (NPS) Pollution Control project has been funded wholly by the United States Environmental Protection Agency (EPA) through a Part 319 grant to the Michigan Department of Environmental Quality. This study is in support of a NPS Black River watershed planning grant, 2007-0114. The contents of the document do not necessarily reflect the views and policies of the EPA, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

The cover depicts the streams, rivers, and ground elevations of the Black River Watershed. Lighter colors are higher elevations.

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Summary

This hydrologic study of the Black River watershed was conducted by the Hydrologic Studies Unit (HSU) of the Michigan Department of Environmental Quality (MDEQ) to better understand the watershed's hydrologic characteristics. The project supports the NPS Black River watershed planning grant to the Sanilac Conservation District.

Hydrologic characteristics of the watershed were evaluated to provide a basis for stormwater management to protect streams from increased erosion and flooding and to help determine the watershed management plan's critical areas. Local governments within the watershed could use the information to help develop stormwater ordinances. Watershed stakeholders may combine this information with other determinants, such as open space preservation, to decide which locations are the most appropriate for wetland restoration, stormwater infiltration or detention, in-stream Best Management Practices (BMPs), or upland BMPs.

Hydrologic modeling quantifies changes in stormwater runoff from 1800 to 1978 due to land use changes. The loss of wetland and the establishment of agricultural and urban land uses are the most noticeable land use transitions during this period. Agriculture is now the dominant land use throughout the watershed. Port Huron is the largest urban land use area. The largest natural land use areas are Minden City and Port Huron State Game Areas. Three percent of the watershed is public land or protected by conservation easements. Three percent of the Black River and its tributaries are designated trout streams.

The 50 percent chance (2-year) 24-hour storm is used in the hydrologic modeling. Relatively modest, but frequent, storm events, such as the 50 percent chance storm, have more effect on channel form than extreme flood flows. Unless properly managed, increases in runoff from 1- to 2-year storms increase channel-forming flows, which increase streambank and bed erosion as the stream enlarges to accommodate the higher flows. Increasing flashiness has been identified at one of five USGS gages in the Black River watershed. However, only one gage has enough recent data to demonstrate that it does not have an increasing flashiness trend.

Based on high flows for USGS gages 04159492 and 04159900 and weather data, the Black River watershed tends to be a snowmelt-driven system. A snowmelt-driven system is usually much less flashy than storm-driven systems, because the snow pack supplies a steadier rate of flow. However, a rain-on-snow event, where rain and snowmelt simultaneously contribute to runoff, can produce dramatic flow increases. The runoff from the rain and snowmelt also likely occur with saturated or frozen soil conditions, when the ground can absorb or store less water, resulting in more overland flow to surface waters than would occur otherwise.

Watershed Description

Overview

The 710 square mile Black River watershed, Figure 1, includes portions of four Michigan counties. The river outlets to the St. Clair River at Port Huron in St. Clair County.

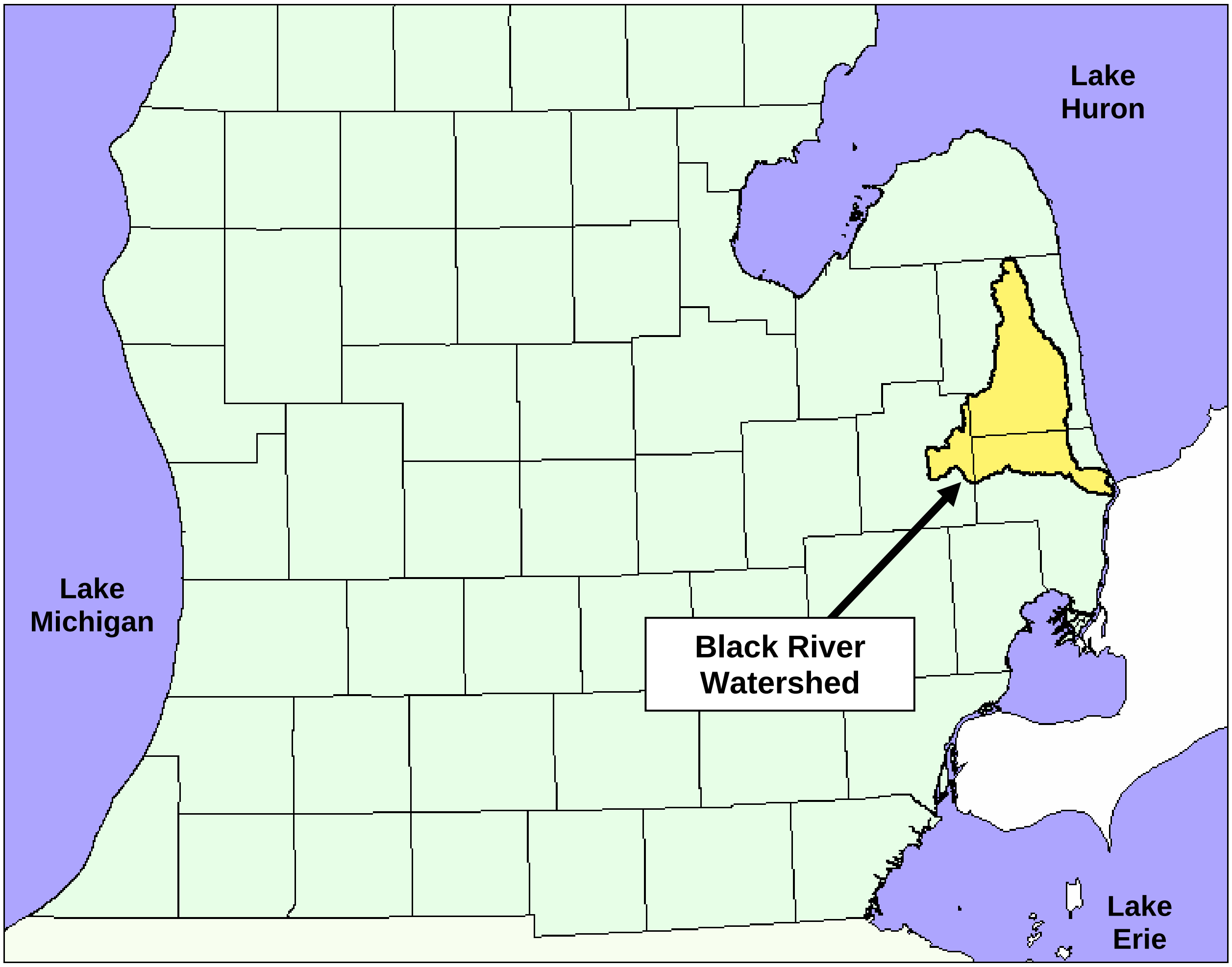


Figure 1 – Black River Watershed Location

A stream's ability to move sediment, both size and quantity, is directly related the stream's slope and flow. Thus steeper reaches generally move larger material, such as stones and pebbles, and the flatter reaches tend to accumulate sediment. According to Rosgen, 1996, "generally, channel gradient decreases in a downstream direction with commensurate increases in streamflow and a corresponding decrease in sediment size." A typical river profile is steeper in the headwaters and flatter toward the mouth. The profile of Black River and its major tributaries, Figure 2, is somewhat different, with flatter reaches in the middle of both the mainstem of the Black River and its largest tributary, Mill Creek. The flatter reaches are likely a reflection of the underlying geology and not an indicator of morphologic instability. The watersheds for the Black River and its major tributaries are shown in Figure 3.

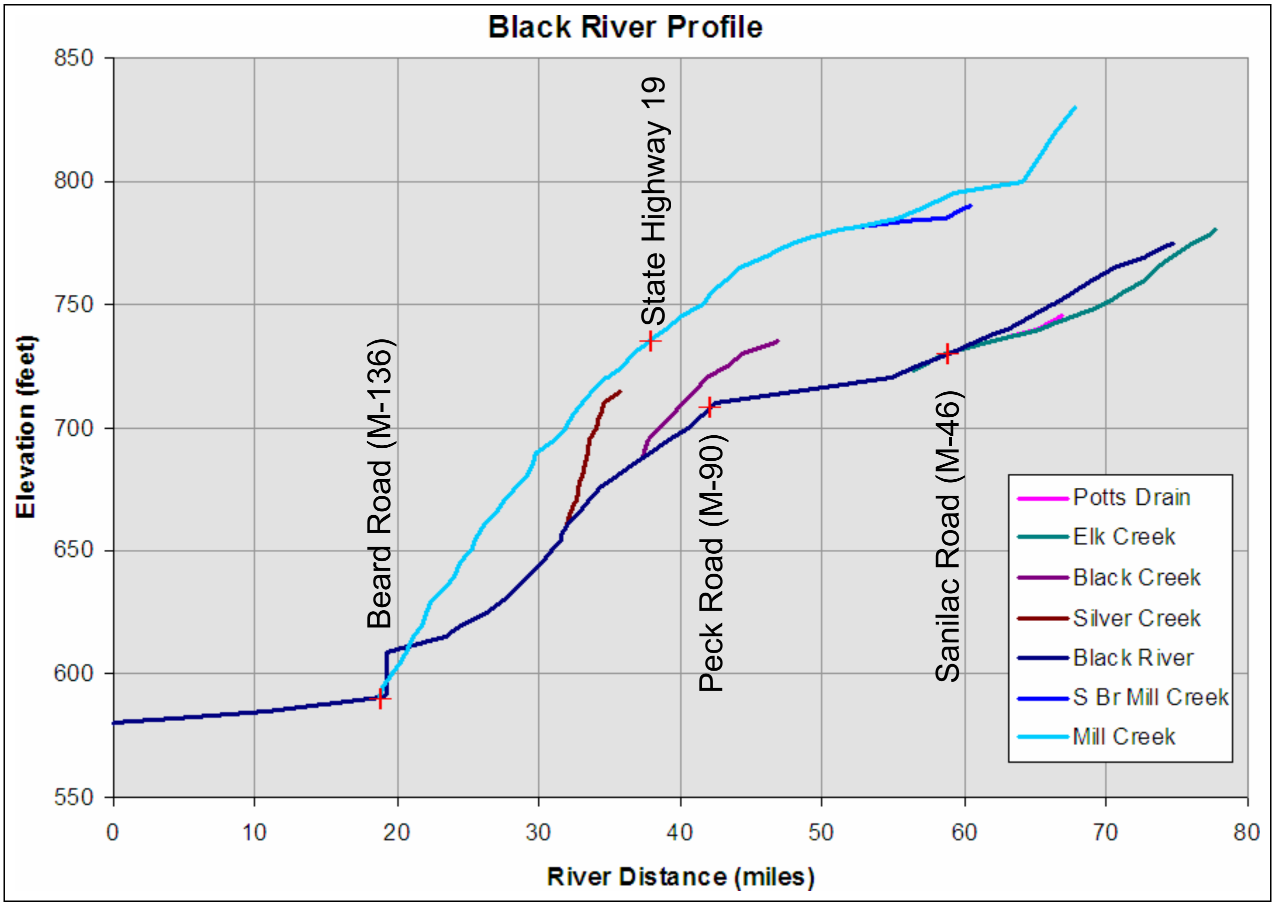


Figure 2: Profile of Black River and its major tributaries

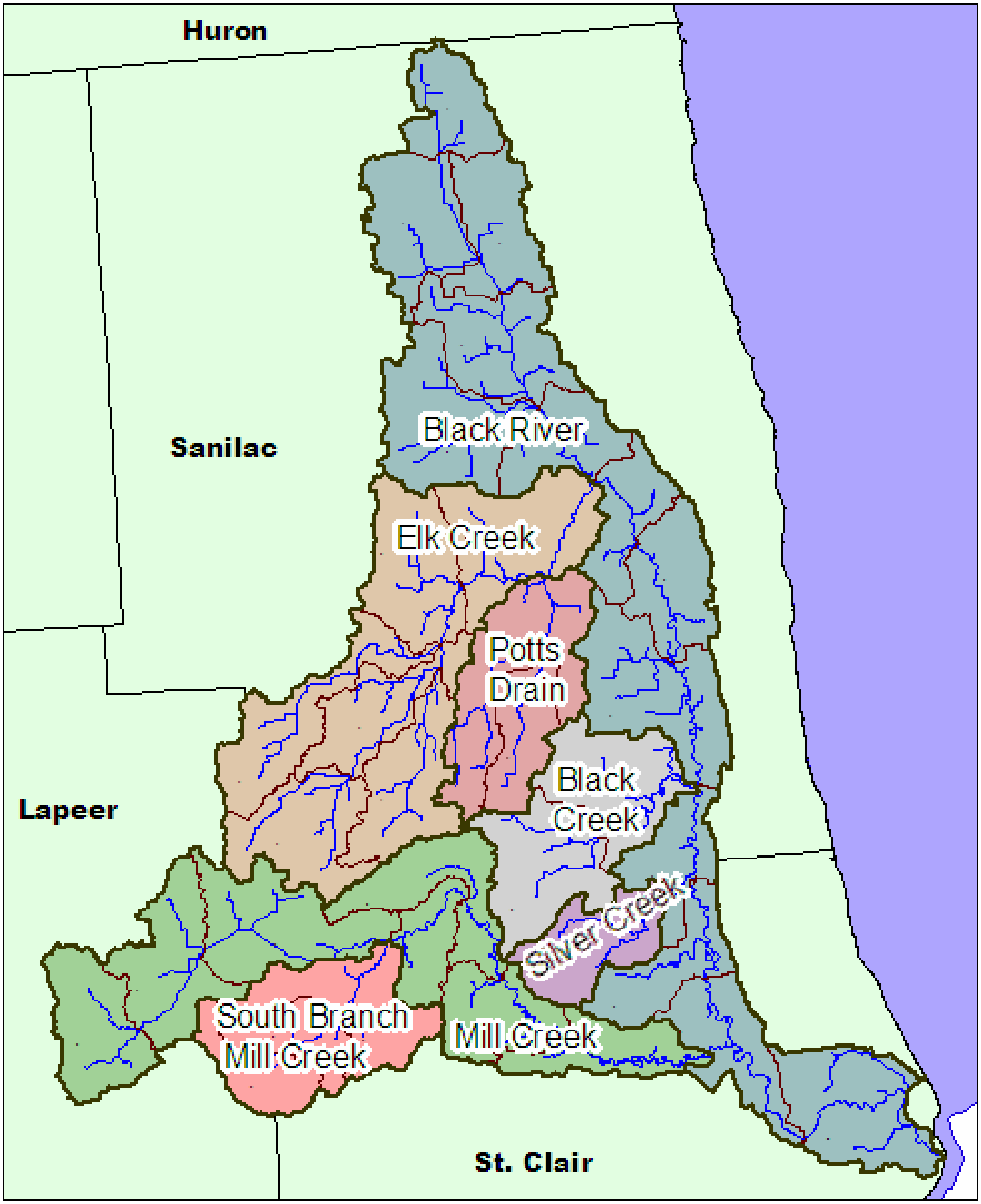


Figure 3: Watersheds for the Black River and its major tributaries

Trout Streams

Approximately three percent of the Black River and its tributaries are designated trout streams, as shown in Figure 4. Trout streams are associated with high quality waters and a good supply of groundwater-fed baseflow, which helps keep the stream flows and temperatures steady.

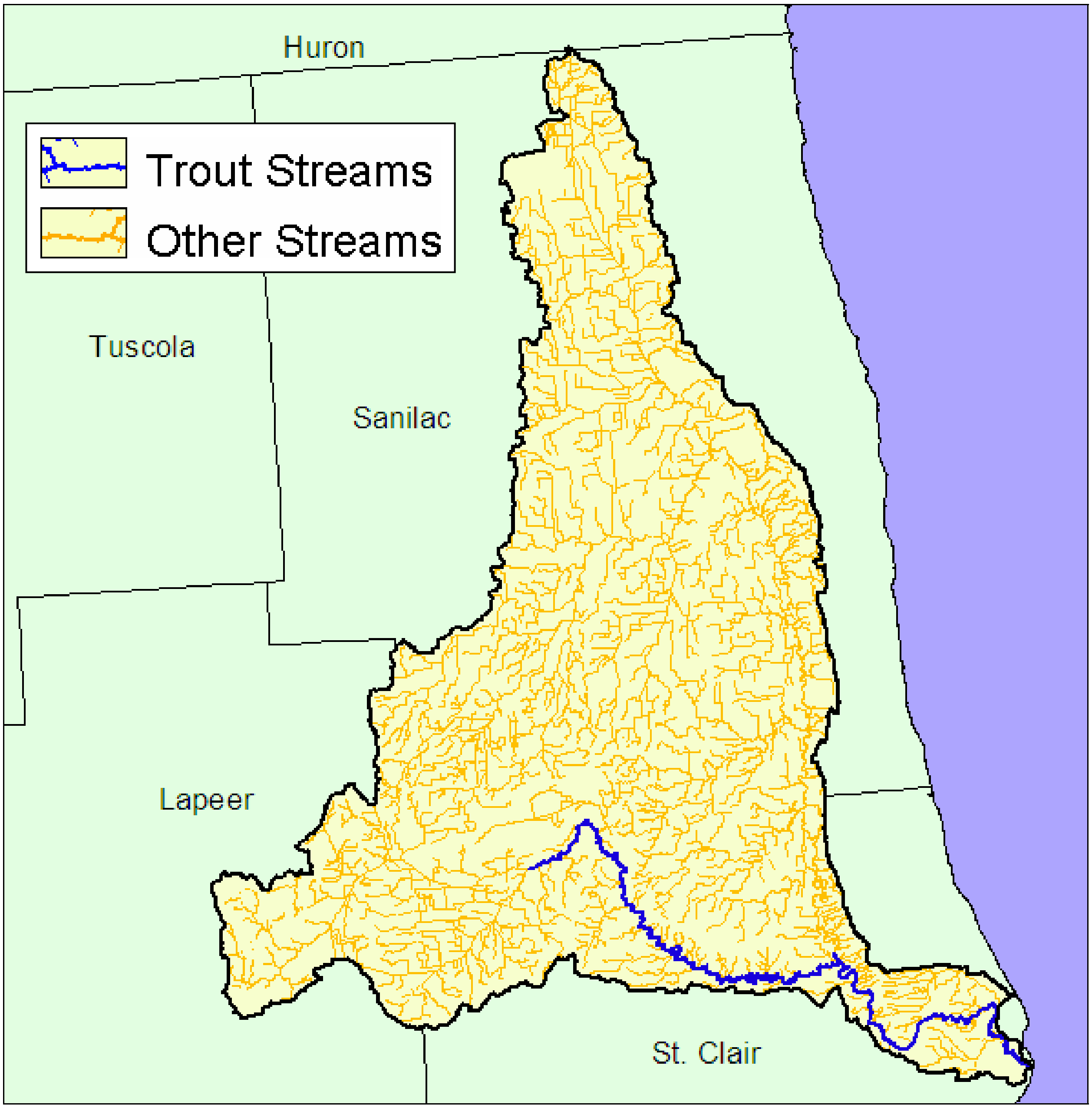


Figure 4 – Black River watershed trout streams and lakes

Stream Order

Stream order is a numbering sequence which starts when two first order, or headwater, streams join, forming a second order stream, and so on. Two second order streams converging form a third order. Streams of lower order joining a higher order stream do not change the order of the higher, as shown in Figure 5. Stream order provides a comparison of the size and potential power of streams.

The Michigan Department of Natural Resources (MDNR) Institute for Fisheries Research and the United States Geological Survey (USGS) Great Lakes Gap have nearly completed a three-year EPA-funded study that provides Geographic Information Systems (GIS) stream order data for Michigan's streams using the 1:100,000 National Hydrography Dataset (NHD). The Black River watershed results are shown in Figure 6.

The stream orders shown are not absolute. If larger scale maps are used or actual channels are found through field reconnaissance, the stream orders designated in Figure 6 may increase, because smaller channels are likely to be included. A more detailed analysis, based on 1:24,000 NHD layer, is being developed.

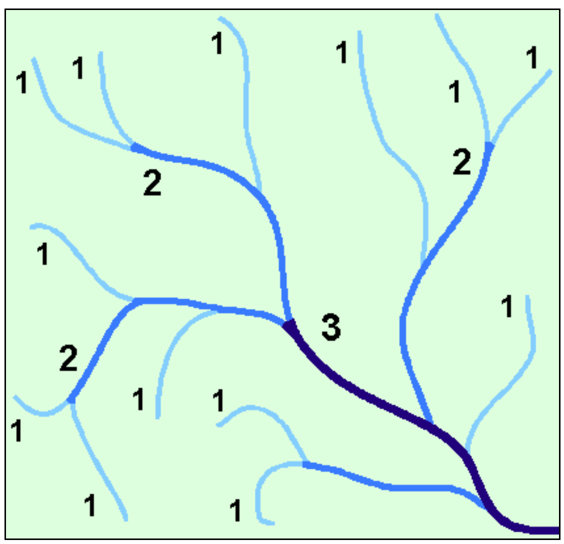


Figure 5 – Stream Ordering Procedure

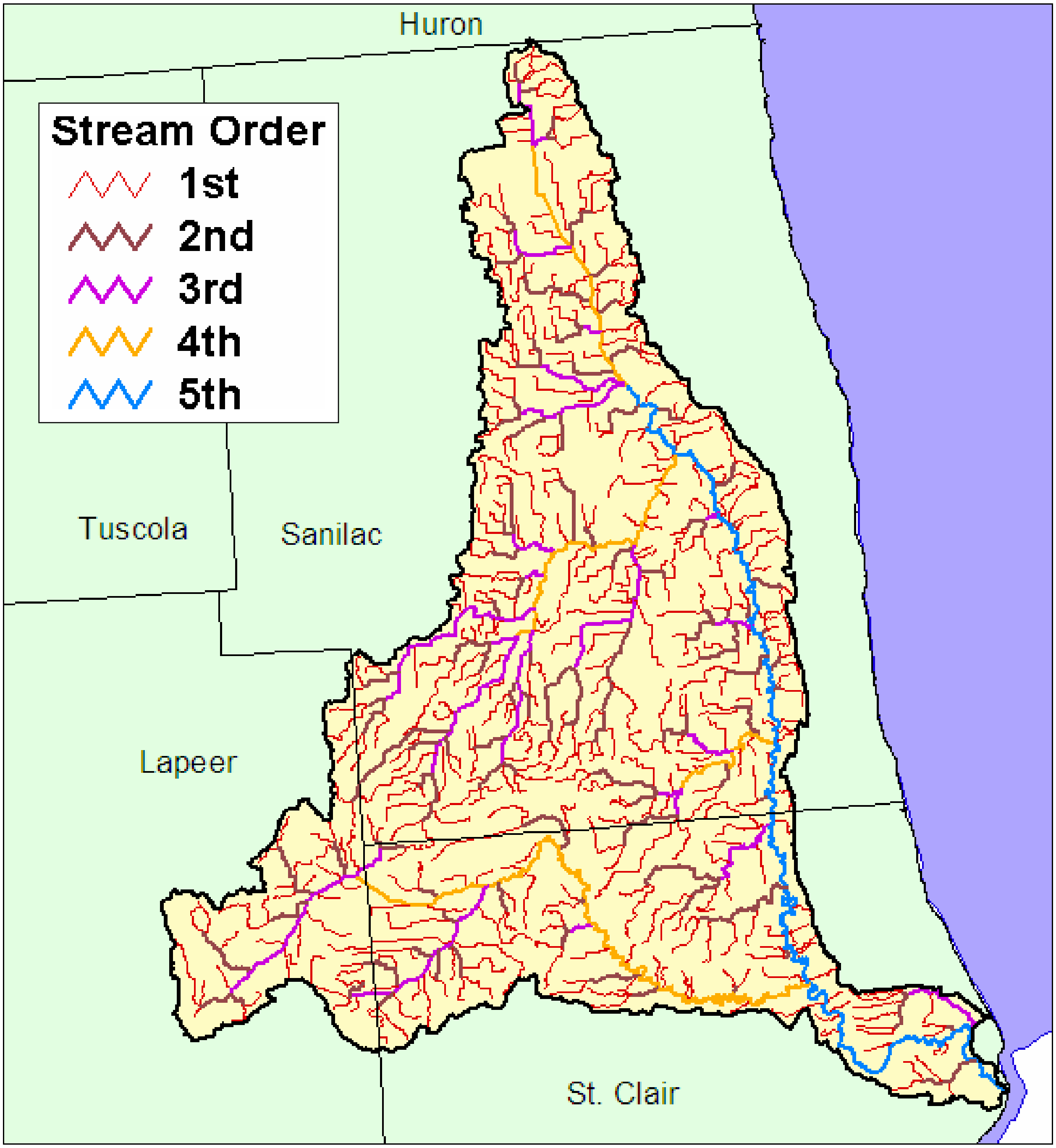


Figure 6 – Black River Watershed Stream Orders

Subbasins

This study divides the watershed into 34 subbasins, Figure 7. The subbasin delineations are available from the Michigan Geographic Data Library, www.mcgi.state.mi.us/mgdl/. Drainage areas are provided in Table 4 (page 18) or Appendix A.

1	Black River below Darlington Drain	18	Black Creek below Jackson Creek
2	Black River above Bishop Drain	19	Black Creek at Mouth
3	Black River below Pelton Drain	20	Silver Creek at Gage #04159488
4	Berry Drain at Mouth	21	Black River at Gage #04159492
5	Black River below Berry Drain	22	Black River at Gage #04159500
6	Elk Creek below Lapee and Sanilac Drain	23	South Branch Mill Creek below Weitzig Drain
7	E. Br. Speaker and Maple Valley Dr. at Mouth	24	South Branch Mill Creek below Kolb Drain
8	Elk Creek above McDonald Drain	25	South Branch Mill Creek at Mouth
9	McDonald Drain at Mouth	26	Elk Lake Creek below Brant Lake Drain
10	Elk Creek below Beals and Frizzle Drain	27	North Branch Mill Creek below Madison Drain
11	Potts Drain above Spring Creek Drain	28	North Branch Mill Creek at Mouth
12	Potts Drain at Mouth	29	Mill Creek below Sanilac & St Clair Drain
13	Elk Creek at Mouth	30	Mill Creek above Sheehy Drain
14	Black River below Elk Creek	31	Mill Creek at Gage #04159900
15	Black River below Papst Drain	32	Mill Creek at Gage #04160000
16	Black River above Arnot Drain	33	Black River at Gage #04160050
17	Black River above Black Creek	34	Black River at Mouth

Figure 7 – Black River Subbasin Identification

Land Use

1800 and 1978 Land Cover

General land use trends for the watershed from 1800 to 1978 are illustrated in Figure 8. More detailed information for each subbasin is tabulated in Table 1 (page 13). Land use maps depicting MDEQ GIS data for 1800 and 1978 are shown in Figures 9 and 10.

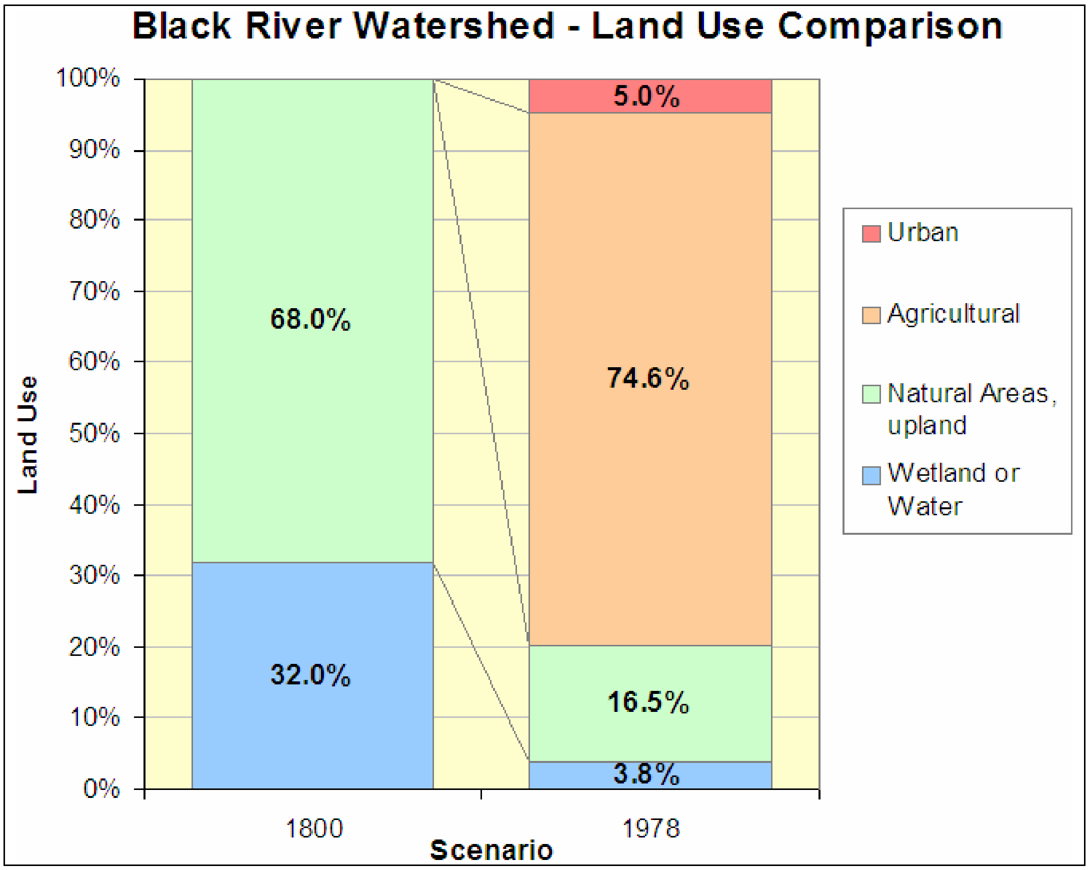


Figure 8 – Land Use Comparison, Black River Watershed

Land use circa 1800 is from a statewide database based on original surveyors' tree data and descriptions of the vegetation and land between 1816 and 1856. Michigan was systematically surveyed during that time by the General Land Office, which had been established by the federal government in 1785. The detailed notes taken by the land surveyors have proven to be a useful source of information on Michigan's landscape as it appeared prior to widespread European settlement. The database creators recognize that there are errors in the database due to interpretation and data input. The MDEQ NPS Program does not expect flow regimes calculated from 1800 land use be used as criteria for BMP design or as a goal for watershed managers.

The 1978 land cover files represent a compilation of data from county and regional planning commissions or their subcontractors. This data set is intended for general planning purposes. It is not intended for site specific use. Data editing, manipulation, and evaluation was completed by the Michigan State University Center for Remote

Sensing and GIS and by the MDNR. Files have been checked by MDNR against original MDNR digital files for errant land cover classification codes.

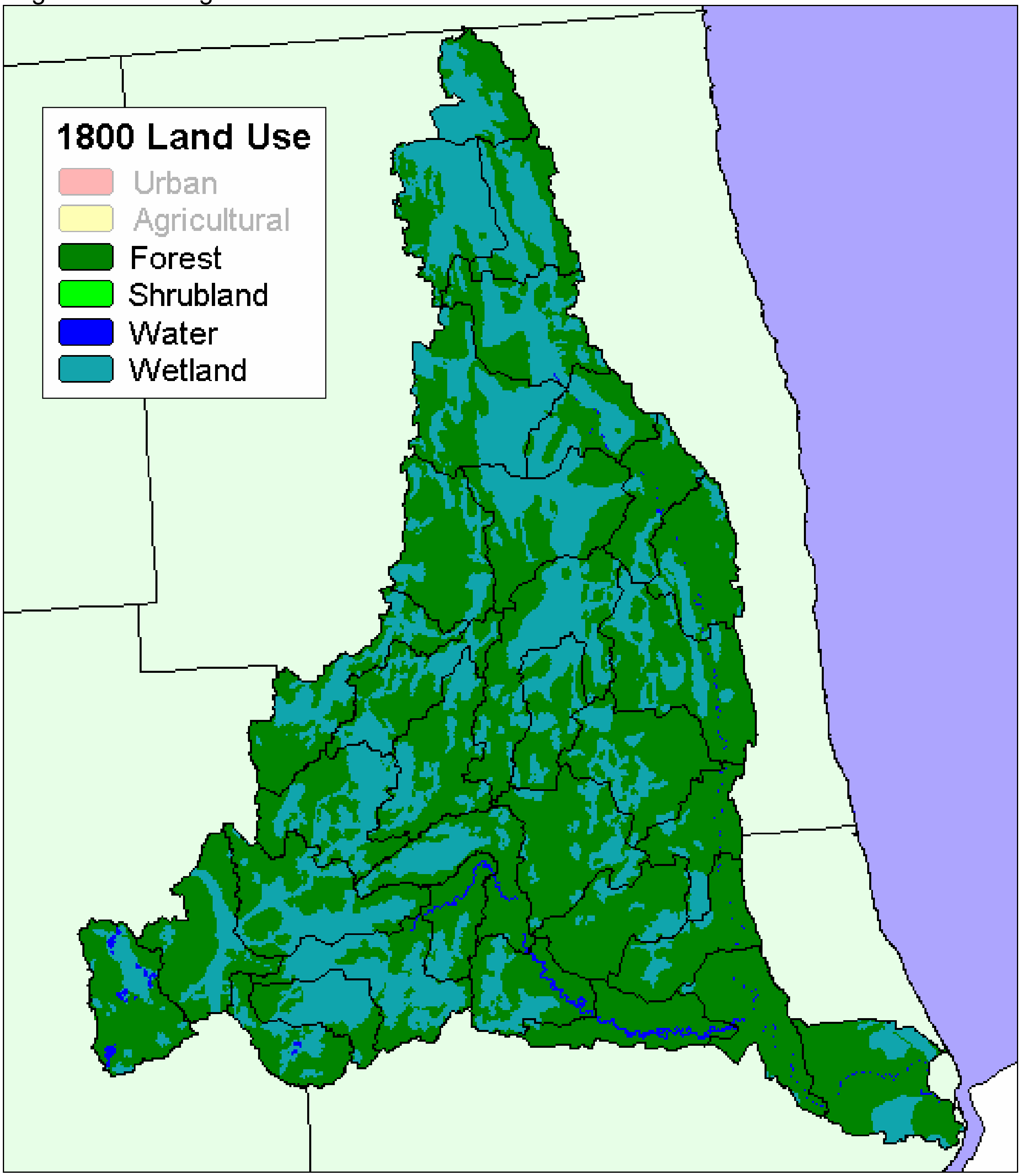


Figure 9 – 1800 Land Cover

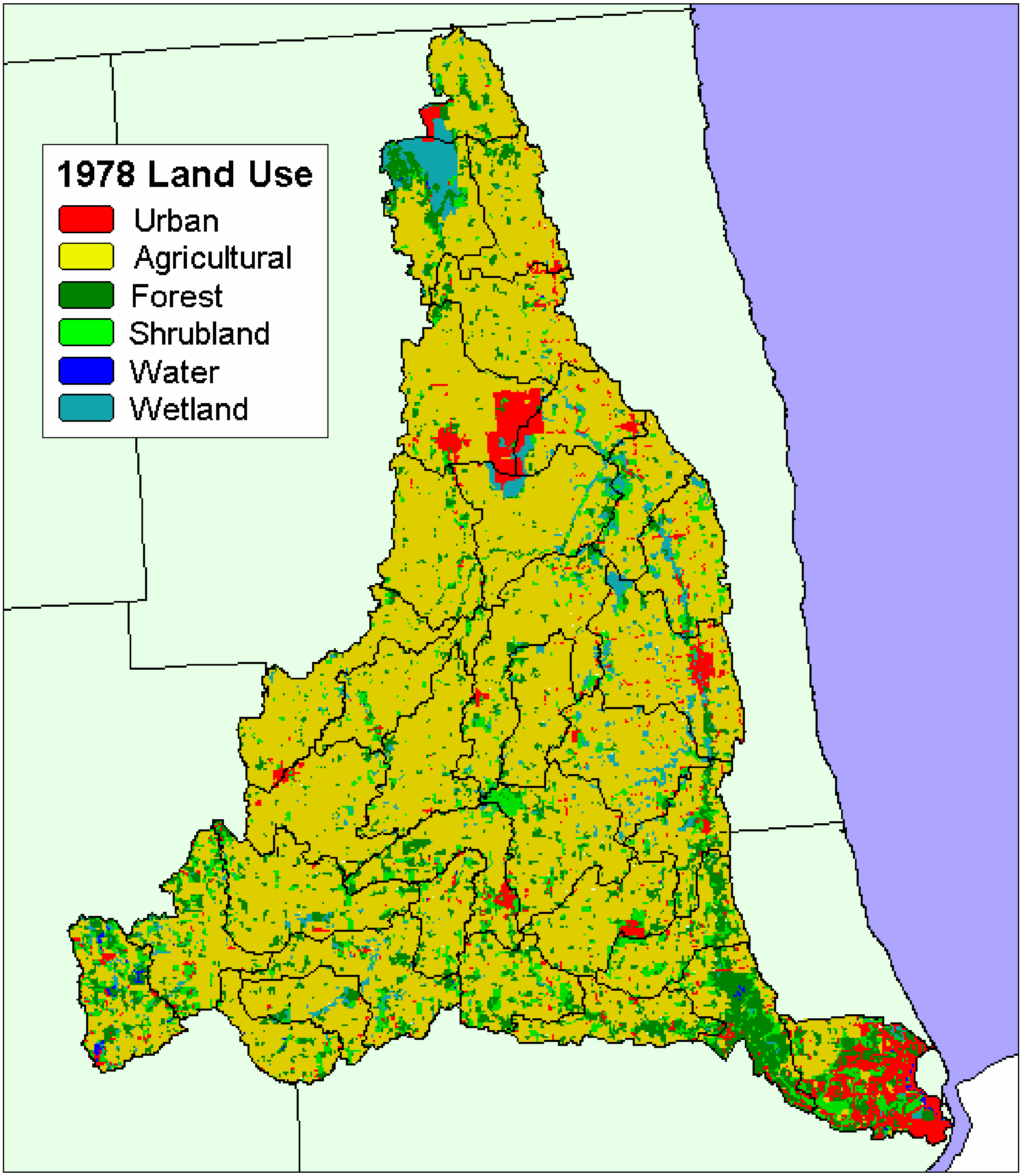


Figure 10 – 1978 Land Cover

Table 1 – Land Use

Subbasin	Scenario	Urban	Agriculture	Herbaceous Open Land	Forest	Open Water	Wetland	Bare Soil, Dune
1	1800				52.5%		47.5%	
	1978	5.3%	73.4%	4.2%	11.3%		5.9%	
2	1800				28.6%		71.4%	
	1978	1.0%	49.3%	5.4%	19.8%	0.1%	24.4%	
3	1800				48.3%		51.7%	
	1978	2.0%	87.7%	0.8%	9.1%		0.4%	
4	1800				44.0%		56.0%	
	1978	20.5%	72.0%	2.3%	4.4%		0.8%	
5	1800				54.0%		46.0%	
	1978	3.0%	88.3%	2.6%	5.4%	0.1%	0.6%	
6	1800				57.1%		42.9%	
	1978	2.0%	91.2%	3.0%	3.0%		0.8%	
7	1800				72.6%		27.4%	
	1978	0.4%	90.2%	2.3%	5.6%		1.5%	
8	1800				63.1%		36.9%	
	1978	0.7%	87.9%	4.7%	6.1%		0.5%	
9	1800				60.6%		39.4%	
	1978	1.3%	91.2%	2.4%	4.1%		1.0%	
10	1800				78.5%		21.5%	
	1978	0.7%	89.7%	3.0%	6.6%	0.1%		
11	1800				63.0%		37.0%	
	1978	0.7%	88.6%	1.9%	6.9%		1.9%	
12	1800				57.4%		42.6%	
	1978	1.9%	83.5%	5.3%	6.3%		2.9%	
13	1800				55.5%	0.2%	44.3%	
	1978	2.2%	82.6%	3.7%	4.8%		6.7%	
14	1800				54.6%	0.4%	45.0%	
	1978	13.0%	72.7%	4.0%	2.5%		7.8%	
15	1800				82.7%	0.5%	16.8%	
	1978	3.1%	75.1%	8.1%	5.3%		8.3%	
16	1800				85.7%	0.5%	13.8%	
	1978	3.6%	75.1%	8.5%	4.4%		8.4%	
17	1800				73.5%	0.4%	26.0%	
	1978	7.5%	74.6%	4.2%	4.8%		8.8%	
18	1800				84.1%		15.9%	
	1978	1.5%	79.5%	8.4%	8.8%		1.8%	
19	1800				80.1%		19.9%	
	1978	2.4%	81.7%	4.9%	2.0%		8.9%	
20	1800				89.7%		10.3%	
	1978	3.6%	82.2%	5.0%	9.0%		0.2%	
21	1800				84.9%	0.8%	14.3%	
	1978	3.8%	68.5%	9.5%	14.5%	0.2%	3.4%	
22	1800				90.2%	0.8%	9.0%	
	1978	2.2%	66.7%	12.1%	18.4%	0.1%	0.3%	0.1%
23	1800				75.5%	0.3%	24.2%	
	1978	0.8%	83.5%	5.2%	9.5%	0.4%	0.6%	
24	1800				41.8%		58.2%	
	1978	0.9%	83.2%	3.3%	8.3%		4.2%	

Subbasin	Scenario	Urban	Agriculture	Herbaceous Open Land	Forest	Open Water	Wetland	Bare Soil, Dune
25	1800				42.9%		57.1%	
	1978	1.5%	75.7%	6.5%	11.7%	0.1%	4.4%	
26	1800				82.6%	1.9%	15.5%	
	1978	5.1%	54.9%	13.8%	18.6%	2.3%	5.3%	
27	1800				75.6%		24.4%	
	1978	2.3%	69.2%	13.1%	12.3%	0.1%	3.0%	
28	1800				61.0%		39.0%	
	1978	0.9%	82.7%	5.3%	9.4%		1.6%	
29	1800				83.3%	0.7%	16.0%	
	1978	1.7%	81.2%	7.9%	8.4%	0.2%	0.5%	
30	1800				73.2%	0.2%	26.6%	
	1978	4.7%	70.4%	11.8%	11.3%		1.7%	
31	1800				75.0%	0.7%	24.4%	
	1978	1.4%	70.0%	13.3%	14.6%		0.7%	
32	1800				98.0%	1.0%	0.9%	
	1978	2.7%	69.4%	8.2%	19.3%		0.3%	0.1%
33	1800				97.5%	1.2%	1.3%	
	1978	6.1%	31.4%	13.7%	47.4%	0.6%	0.8%	
34	1800				78.3%	1.3%	20.4%	
	1978	41.5%	20.1%	17.1%	18.7%	0.9%	1.6%	0.1%
All	1800				68.0%	0.3%	31.7%	
	1978	5.0%	74.6%	6.5%	10.0%	0.2%	3.6%	

Imperviousness

Percent imperviousness can be compared to the Center for Watershed Protection's Impervious Cover Model (ICM) for headwater urban streams, excerpted in Table 2 and detailed in *The Importance of Imperviousness, The Practice of Watershed Protection* (Schueler and Holland, 2000). In May 2008, three refinements to the ICM were presented by Tom Schueler, Chesapeake Stormwater Network, and Lisa Fraley-McNeal, Center for Watershed Protection, at the 2nd Symposium on Urbanization and Stream Ecology (www.rivercenter.uga.edu/research/urban/urban_meeting3.htm). Figure 11 shows the revised figure, adapted with permission. The three refinements as described by Fraley-McNeal (2008) are:

1. The imperviousness/stream quality relationship is now a cone rather than a line. The cone represents the observed variability in stream quality and also the typical range in expected improvement that could be attributed to subwatershed treatment. The cone illustrates that most regions show a generally continuous but variable gradient of stream degradation as impervious cover increases.

2. The cone width is greatest for impervious cover values less than 10 percent, which reflects the wide variability in stream quality observed for these streams. This prevents the misperception that streams with low impervious cover will automatically possess good or excellent quality. The expected quality of streams in this range of impervious cover is generally influenced more by other watershed

characteristics such as forest cover, road density, riparian continuity, and cropping practices.

3. The transition between stream quality classifications is now a band rather than a fixed line. If specific values are used to separate stream categories, the values should be based on actual monitoring data for the ecoregion, the stream indicators of greatest concern, and the predominant predevelopment regional land cover (e.g., crops or forest).

To properly apply and interpret the ICM in a watershed context:

- Watershed scale matters. The use of the ICM should generally be restricted to first to third order alluvial streams.
- The ICM may not work well in subwatersheds with major pollutant point sources, or extensive impoundments or dams within the stream network.
- The ICM is best applied to subwatersheds located within the same physiographic region. In particular, stream slopes, as measured from the top to the bottom of subwatersheds, should be in the same general range.
- The ICM is unreliable when management practices are poor, particularly when impervious cover levels are low (e.g., deforestation, acid mine drainage, intensive row crops, denudation of riparian cover).

When these caveats are applied, the available science generally reinforces the validity of the ICM as a watershed planning tool to forecast the general response of freshwater and tidal streams as a result of future land development.

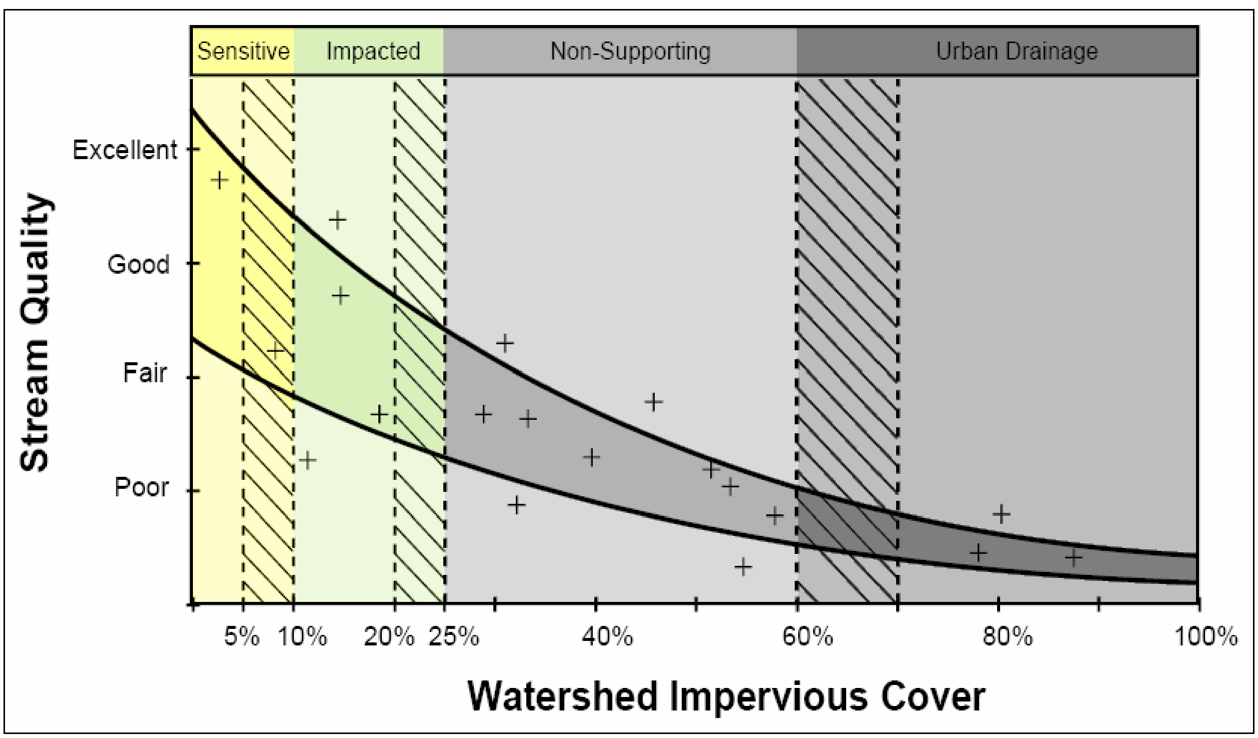


Figure 11 – Impervious Cover Model, adapted with permission (Fraley-McNeal 2008)

Table 2 – Classification of Urban Headwater Streams

Urban Stream Classification	Sensitive	Impacted	Non-supporting
Channel Stability	Stable	Unstable	Highly unstable
Water Quality	Good	Fair	Fair-Poor
Stream Biodiversity	Good-Excellent	Fair-Good	Poor
Resource Objective	Protect biodiversity and channel stability	Maintain critical elements of stream quality	Minimize downstream pollutant loads

Excerpted from “The Practice of Watershed Protection” by Thomas Schueler and Heather Holland, p. 15

The percent imperviousness of each subbasin was analyzed based on the 1978 land use GIS data, Figure 10. The percent imperviousness was computed according to Table 3. The imperviousness values for residential, commercial, and industrial are from the Natural Resources Conservation Service (NRCS, 1986).

The results, shown in Figure 12 and tabulated in Table 4, indicate that only one of the 34 subbasins have exceeded five percent imperviousness. The expected quality of these streams is generally influenced more by other watershed characteristics such as forest cover, road density, riparian continuity, and cropping practices. None of the subbasins have exceeded the 20 percent at this scale of analysis. However, there may also be headwater streams with smaller drainage areas within any subbasin that exceed the thresholds for impacted or non-supporting streams. With proper planning and BMP selection, the negative impacts associated with the increased imperviousness can be mitigated.

Table 3 – Imperviousness Table for Impervious Area Analysis

GIS Class	Description	Imperviousness (percent)
1	Residential	38*
2	Commercial	85
3	Industrial	72
4	Road, Utilities	95
5	Gravel Pits	0
6	Outdoor Recreation	0
7	Cropland	0
8	Orchard	0
9	Pasture	0
10	Openland	0
11	Forests	0
12	Open Water	0
13	Wetland	0

* assumed population density of 250 to 1,000 people per square mile

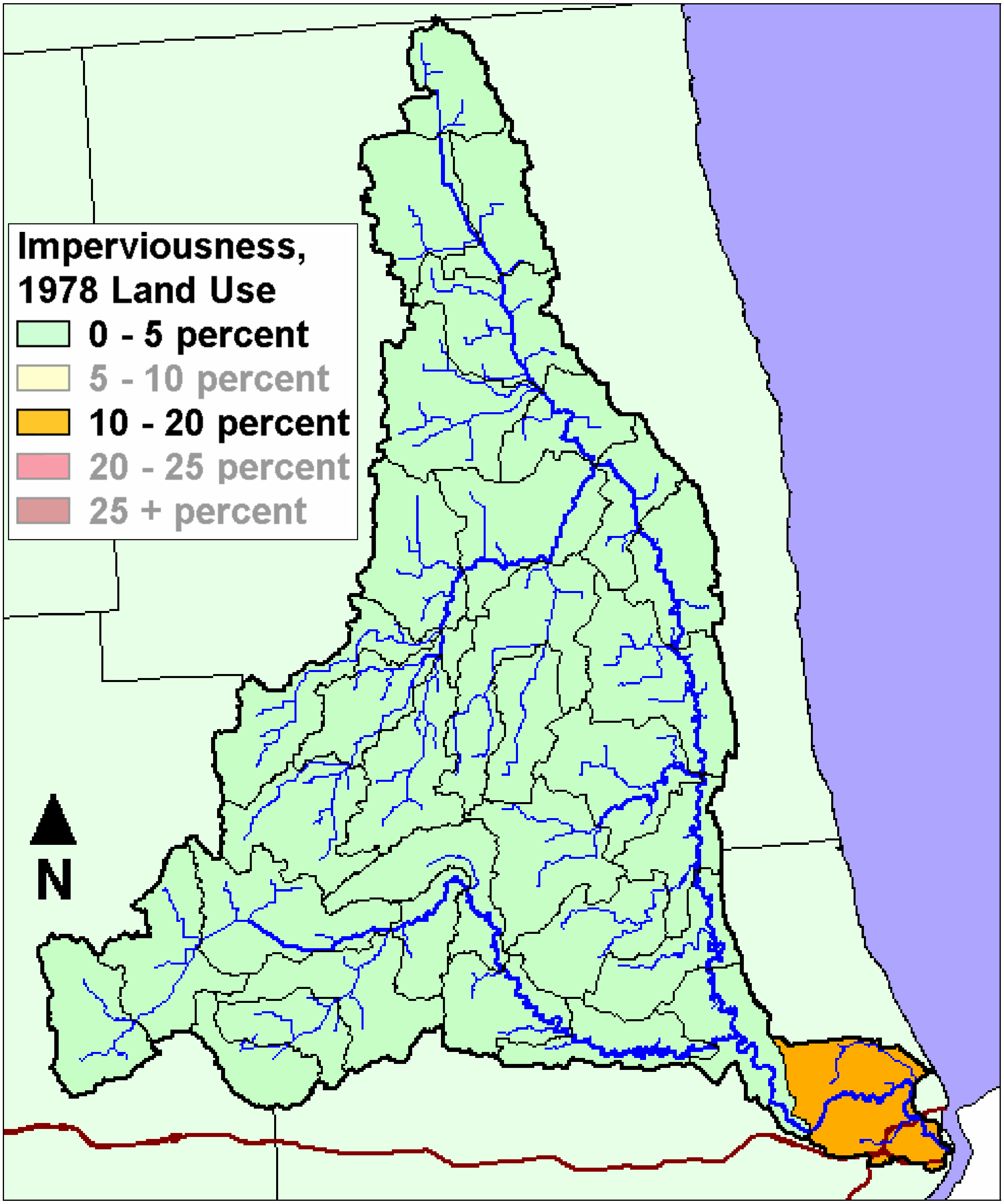


Figure 12 – Percent Imperviousness based on 1978 Land Cover

Table 4 – Percent Imperviousness and Conservation and Recreation Lands

ID	Subbasin	Drainage Area (sq. mi.)	Percent Impervious	Percent CARL
1	Black River below Darlington Drain	14.9	0.8%	0.1%
2	Black River above Bishop Drain	22.2	0.5%	31.8%
3	Black River below Pelton Drain	19.0	2.1%	2.2%
4	Berry Drain at Mouth	29.0	3.4%	0.9%
5	Black River below Berry Drain	24.2	2.1%	0.2%
6	Elk Creek below Lapee and Sanilac Drain	23.8	2.0%	1.1%
7	E. Br. Speaker and Maple Valley Dr. at Mouth	22.5	1.0%	0.1%
8	Elk Creek above McDonald Drain	18.2	1.0%	0.3%
9	McDonald Drain at Mouth	23.6	1.4%	1.6%
10	Elk Creek below Beals and Frizzle Drain	24.1	1.1%	
11	Potts Drain above Spring Creek Drain	15.1	1.1%	
12	Potts Drain at Mouth	31.2	1.5%	
13	Elk Creek at Mouth	28.5	1.1%	
14	Black River below Elk Creek	15.9	2.3%	
15	Black River below Papst Drain	14.6	1.6%	
16	Black River above Arnot Drain	19.4	2.3%	
17	Black River above Black Creek	31.1	4.2%	1.6%
18	Black Creek below Jackson Creek	25.6	1.5%	0.4%
19	Black Creek at Mouth	24.9	1.9%	
20	Silver Creek at Gage #04159488	20.3	3.9%	1.4%
21	Black River at Gage #04159492	14.5	1.3%	2.3%
22	Black River at Gage #04159500	16.9	1.6%	8.7%
23	South Branch Mill Creek below Weitzig Drain	11.9	1.3%	
24	South Branch Mill Creek below Kolb Drain	12.8	1.4%	1.6%
25	South Branch Mill Creek at Mouth	23.2	1.3%	
26	Elk Lake Creek below Brant Lake Drain	20.6	2.4%	1.8%
27	North Branch Mill Creek below Madison Drain	23.2	1.6%	
28	North Branch Mill Creek at Mouth	27.6	0.9%	0.5%
29	Mill Creek below Sanilac & St Clair Drain	11.3	1.1%	
30	Mill Creek above Sheehy Drain	20.3	2.9%	2.0%
31	Mill Creek at Gage #04159900	17.3	1.2%	
32	Mill Creek at Gage #04160000	15.3	1.7%	
33	Black River at Gage #04160050	19.2	2.8%	35.3%
34	Black River at Mouth	27.8	18.2%	4.0%

Conservation and Recreation Lands

With United States Fish and Wildlife Service support, Ducks Unlimited and the Nature Conservancy in Michigan (2007) are creating a comprehensive GIS layer of Michigan's Conservation and Recreation Lands (CARL). The CARL GIS layer consists of public lands (federal, state, and local government-owned lands), private lands (The Nature Conservancy, Audubon, and local conservancies), and some conservation easements (with permission). The CARL layer should be a valuable tool for planning and development of coastal and inland wetland habitat restoration and protection activities. The CARL layer will also assist other land-use planners by formulating informed decisions, including plans for greenways, conservation, and recreational activities. Figure 13 depicts the conservation and recreation lands for the Black River watershed as of May 2007. The area of these lands is 20 square miles, which is three percent of the watershed. Table 4 shows this information for each subbasin. The information is not final but is expected to be reasonably accurate.

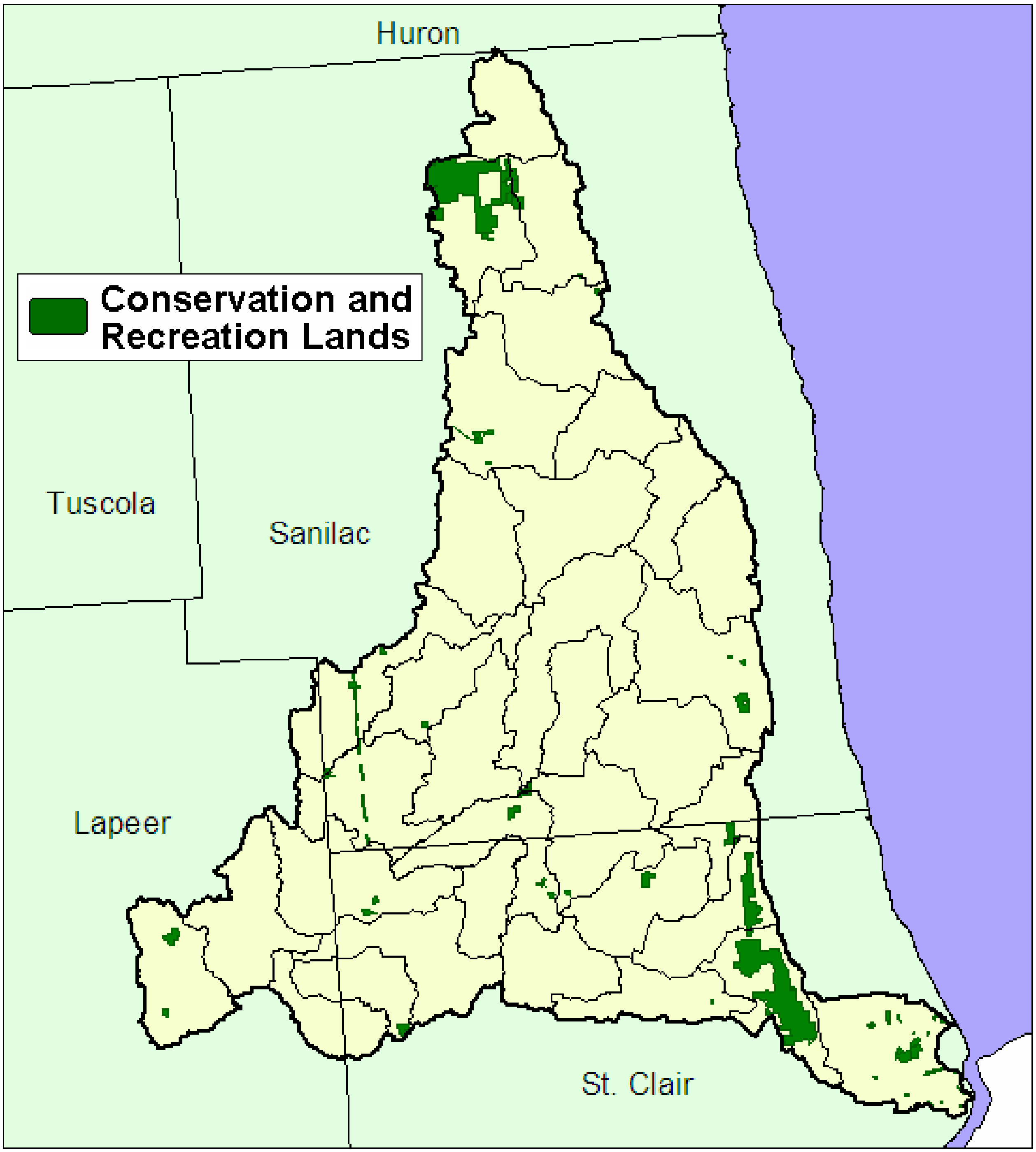


Figure 13 – Conservation and Recreation Lands by Ownership

Soils

Hydrologic soil groups, or hydrogroups, are grouped according to the infiltration of water when the soils are thoroughly wet and receive precipitation from long-duration storms, as described in Table 5. Where the soil is given a dual hydrogroup classification, A/D for example, the soil type selected is based on land use. In these cases, the soil type is specified as D for natural land uses, or the alternate classification (A, B, or C) for developed land uses.

The soils maps resolved for 1800 and 1978 land use are shown in Figures 14 and 15 respectively. The differences in resolved soil hydrogroups from 1800 to 1978, Table 6, are due to agricultural and urban land use transitions and the addition of drains.

Table 5 – Soil Hydrogroups

Hydrologic Soil Group	Infiltration Rate when thoroughly wet	Description
A	High	• Sand • Gravelly sand
B	Moderate	• Moderately fine textured to moderately coarse textured soils
C	Slow	• Moderately fine textured to fine textured soils • Soils with a soil layer that impedes downward movement of water
D	Very Slow	• Clays • Soils with a clay layer near the surface • Soils with a permanent high water table

Table 6 – Areal Extent of Soil Hydrogroups for Entire Watershed

Hydrologic Soil Group	1800 Land Use	1978 Land Use
A	6%	10%
B	19%	50%
C	25%	28%
D	50%	11%

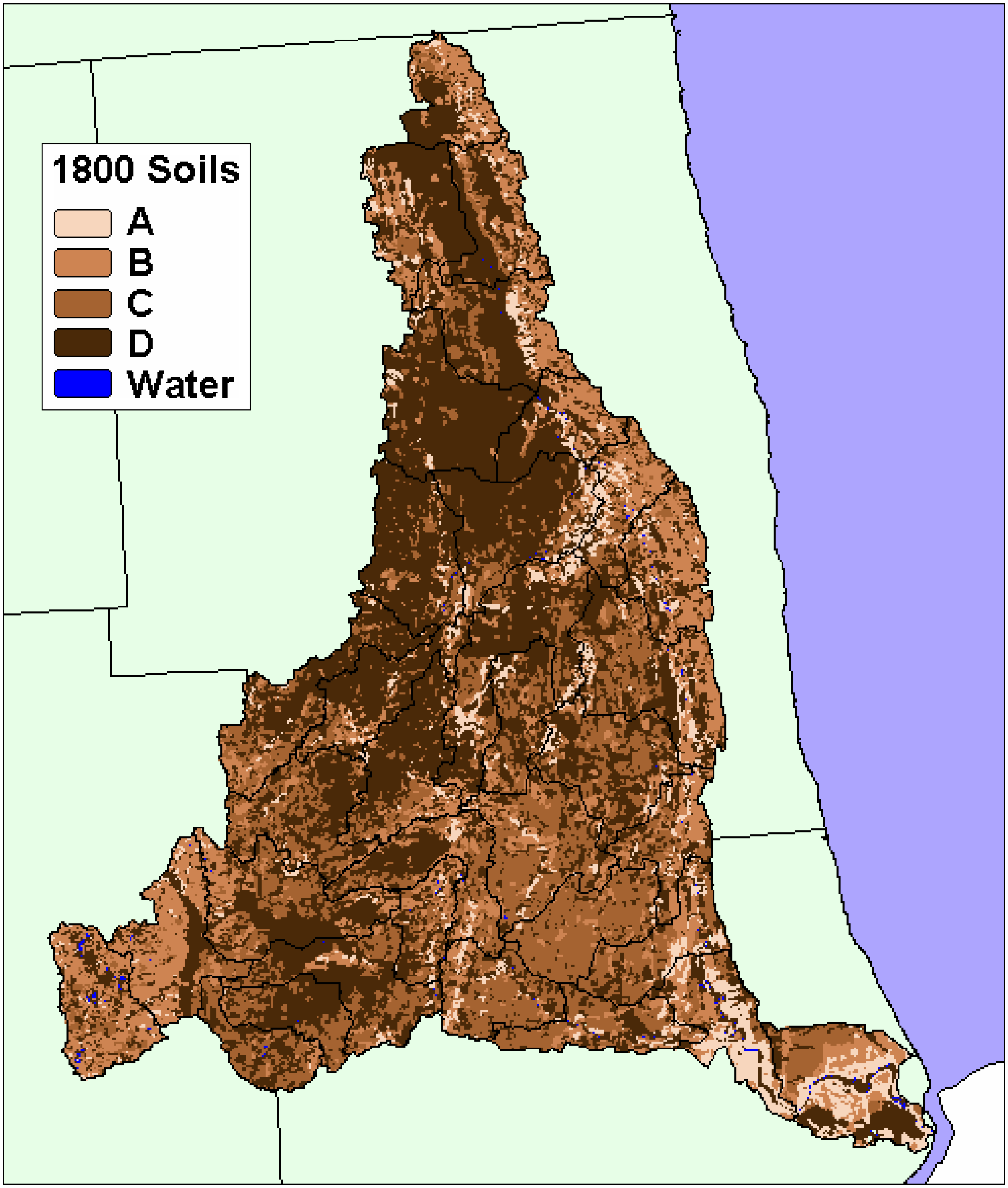


Figure 14 – Soil Hydrogroups, 1800 Land Use

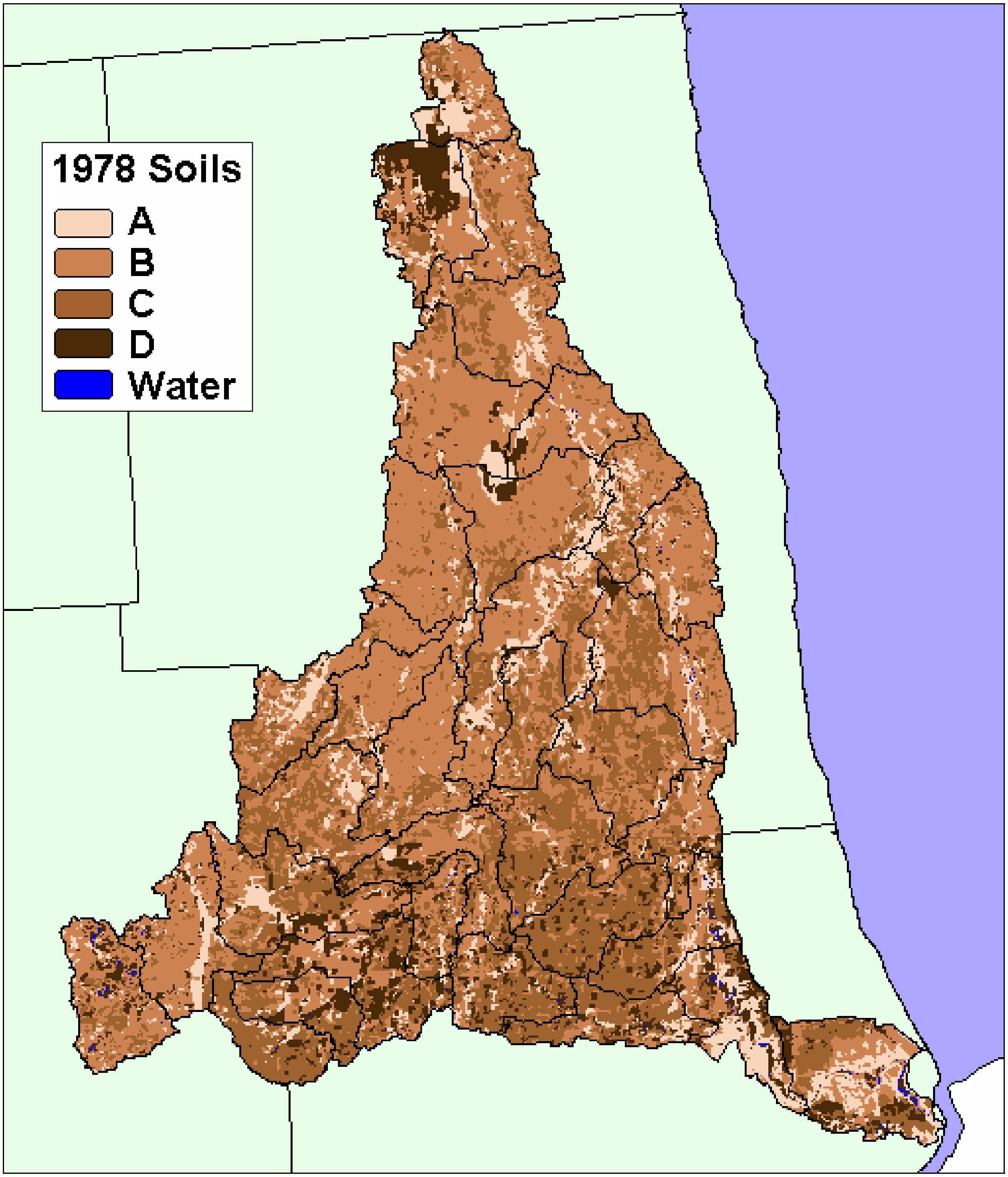
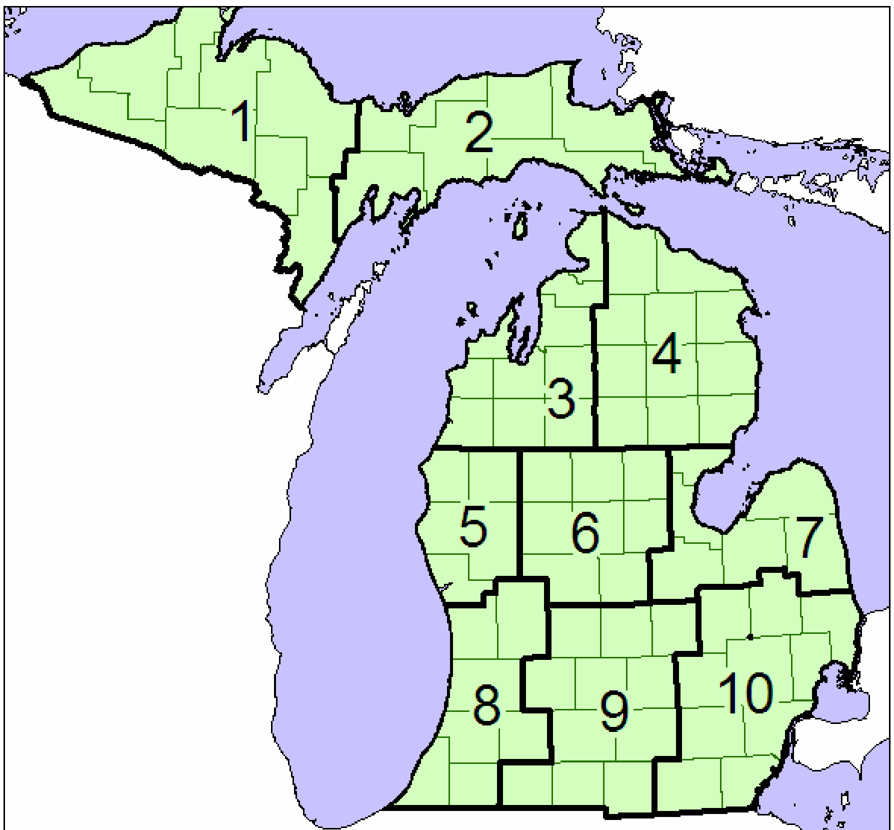


Figure 15 – Soil Hydrogroups, 1978 Land Use

Hydrologic Analysis Parameters

Rainfall

The design rainfall value used in this study is 2.20 inches, corresponding to the average 50 percent chance (2-year) 24-hour storm for the watershed, as tabulated in *Rainfall Frequency Atlas of the Midwest*, Bulletin 71, Midwestern Climate Center, 1992. This storm was selected because runoff from the 50 percent chance storm approximates channel-forming flows assuming the watershed is, and was, a storm-driven system. The Black River watershed spans climatic zones 7 and 10, Figure 16.



Zone	Rainfall frequencies, 24-hour duration (rainfall in inches)					
	2-year	5-year	10-year	25-year	50-year	100-year
1	2.39	3.00	3.48	4.17	4.73	5.32
2	2.09	2.71	3.19	3.87	4.44	5.03
3	2.09	2.70	3.21	3.89	4.47	5.08
4	2.11	2.62	3.04	3.60	4.06	4.53
5	2.28	3.00	3.60	4.48	5.24	6.07
6	2.27	2.85	3.34	4.15	4.84	5.62
7	2.14	2.65	3.05	3.56	3.97	4.40
8	2.37	3.00	3.52	4.45	5.27	6.15
9	2.42	2.98	3.43	4.09	4.63	5.20
10	2.26	2.75	3.13	3.60	3.98	4.36

Figure 16 – Rainfall Amounts for Michigan's Climatic Zones (Black River watershed climatic zones highlighted)

Runoff Curve Numbers

Calculations

Surface runoff volumes were modeled using the runoff curve number technique. This technique, developed by the Natural Resources Conservation Service (NRCS) in 1954, represents the runoff characteristics from the combination of land use and soil data as a runoff curve number. The technique, as adapted for Michigan, is described in "Computing Flood Discharges For Small Ungaged Watersheds" (Sorrell, 2008).

The runoff curve numbers (CN) were calculated using GIS technology from the digital land use and soil data shown in Figures 9, 10, 14, and 15. Housing density is a part of the curve number calculations. Average residential lot size was specified as 0.50 acres, except for the Port Huron area, where the lot size was specified as 0.25 acres. Runoff curve numbers for each subbasin are listed in Appendix A. Additional details on the GIS method are at www.michigan.gov/deqhydrology, GIS category, Calculating Runoff Curve Numbers with GIS.

Assumptions and Limitations

P/S Test

An assumption of the runoff curve number technique is that the entire watershed contributes runoff. The curve number technique documentation is the NRCS's Part 630 Hydrology National Engineering Handbook. Chapter 10, Section 630-1003 Accuracy, of this handbook states, "The runoff equation generally did reasonably well where the runoff was a substantial fraction of the rainfall, but poorly in cases where the runoff was a small fraction of the rainfall; i.e., the CNs are low or rainfall values are small. Curve numbers were originally developed from annual flood flows from experimental watersheds, and their application to low flows or small flood peak flows is not recommended. (See Hawkins, et al. 1985, for a precise measure of small.)" According to Hawkins, "relative storm size is then proposed to be defined on the ratio P/S, where a "large" storm has P/S>0.46, when 90 percent of all rainstorms will create runoff." P/S is the ratio of precipitation, P, to potential maximum retention, S. When P/S is less than 0.46, runoff volumes and peak flows for smaller events would depend upon the portion of each subbasin contributing runoff, which will vary with the rainfall total and intensity.

Several of the curve numbers do not meet the P/S test, Table 7, meaning only a portion of a subbasin may be contributing runoff, not the entire subbasin, as assumed in the model. Peak flow and runoff volume results for those areas may be underestimated. This would be particularly true for subbasins with directly connected impervious areas, which generate runoff more quickly from those areas in smaller rain events.

Table 7 – Model results that do not meet the P/S ≥ 0.46 test

Subbasin		Scenario	P/S
4	Berry Drain at Mouth	1978	0.40
15	Black River below Papst Drain	1800	0.44
16	Black River above Arnot Drain	1800	0.44
26	Elk Lake Creek below Brant Lake Drain	1800	0.45
27	N Br Mill Creek below Madison Drain	1800	0.45
33	Black River at Gage #04160050	1800	0.38
		1978	0.44

Snowmelt or Storms

The approximate 1-year recurrence flows for USGS gages 04159492 and 04159900, Figure 18, are 2000 and 550 cfs respectively (Fongers, 2006). Stream flow is most likely to exceed these values in the spring, Figure 17. This suggests that the Black River watershed may be a snowmelt-driven system more than a storm-driven system. In a storm-driven system, rainfalls during the growing season usually generate the flood flows. Snowmelt-driven systems are usually less flashy than storm-driven systems, because the snow pack supplies a steadier rate of flow. However, a rain-on-snow event, where rain and snowmelt simultaneously contribute to runoff, can produce dramatic flow increases. The runoff from the rain and snowmelt also likely occur with saturated or frozen soil conditions, when the ground can absorb or store less water, resulting in more overland flow to surface waters than would occur otherwise.

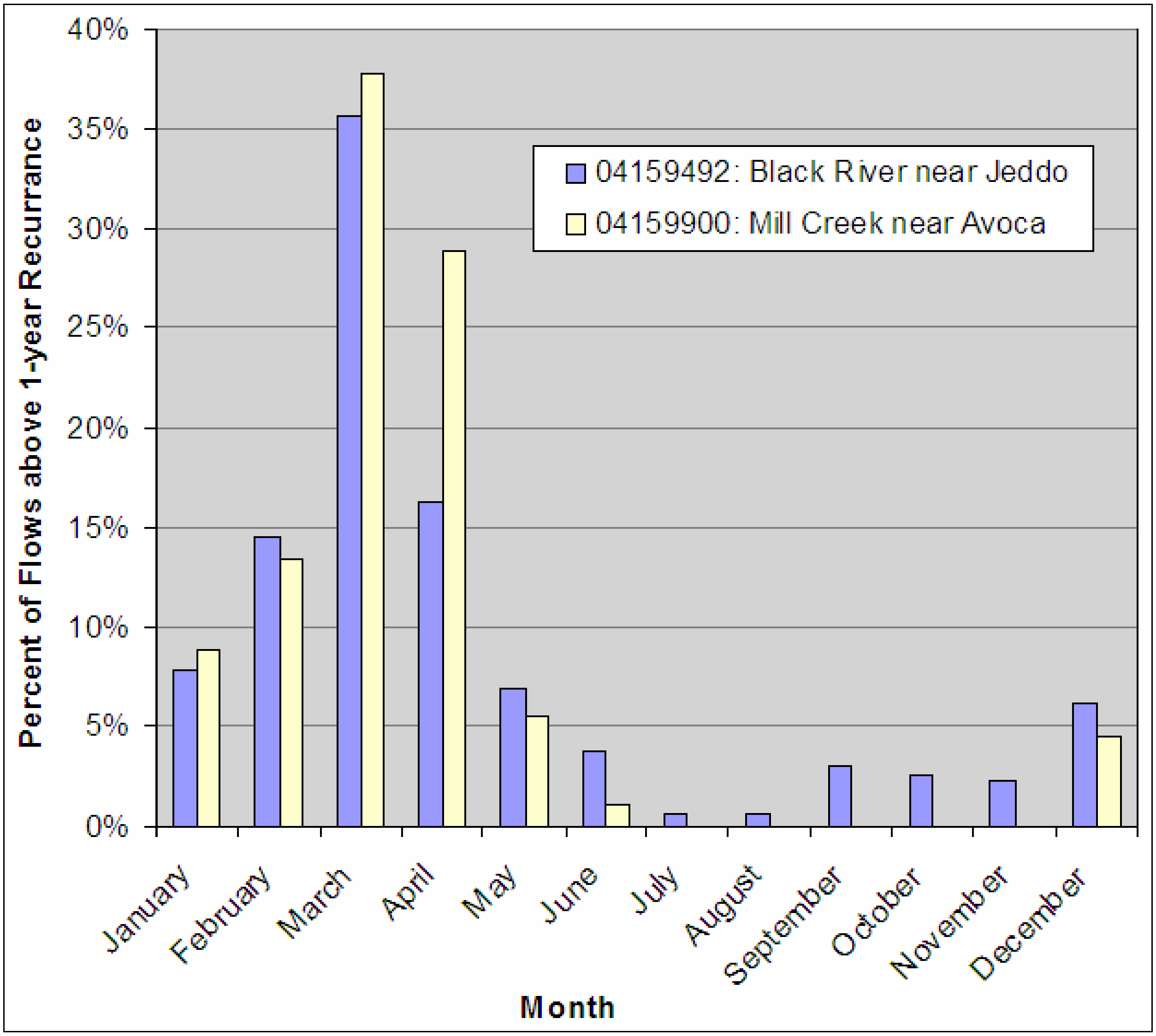


Figure 17 – Percent of Peak Flows above the 1-year recurrence flow by month

Rainfall and soil temperature data for 2005 through 2008 are available for the Sandusky City Airport from the Michigan Automated Weather Network (MAWN), Figure 18, and is shown, along with the USGS gage data in Figures 19 through 22. Recurrences noted on the figures are from on Table 8. The data generally show that most of the highest peaks occur from relatively minor amounts of rain, less than one inch total, on frozen, but thawing ground. On the other hand, larger summer rainfalls, as high as 2.36 inches in July 2005, elicit very little change in stream flow. High flows resulting at least partially from melting snow, as indicated by soil temperatures increasing from 32 degrees Fahrenheit, are apparent on 1/14/2005, 3/23/2005, 3/14/2006, 3/14/2007, and 1/9/2008. Although soil temperature and precipitation is not available from MAWN for 3/5/2008 through 3/27/2008, National Weather Service stations at Sandusky and Yale report only 0.29 to 0.41 inches of precipitation for the period. One or both of the peaks in this period is also likely associated with snowmelt.

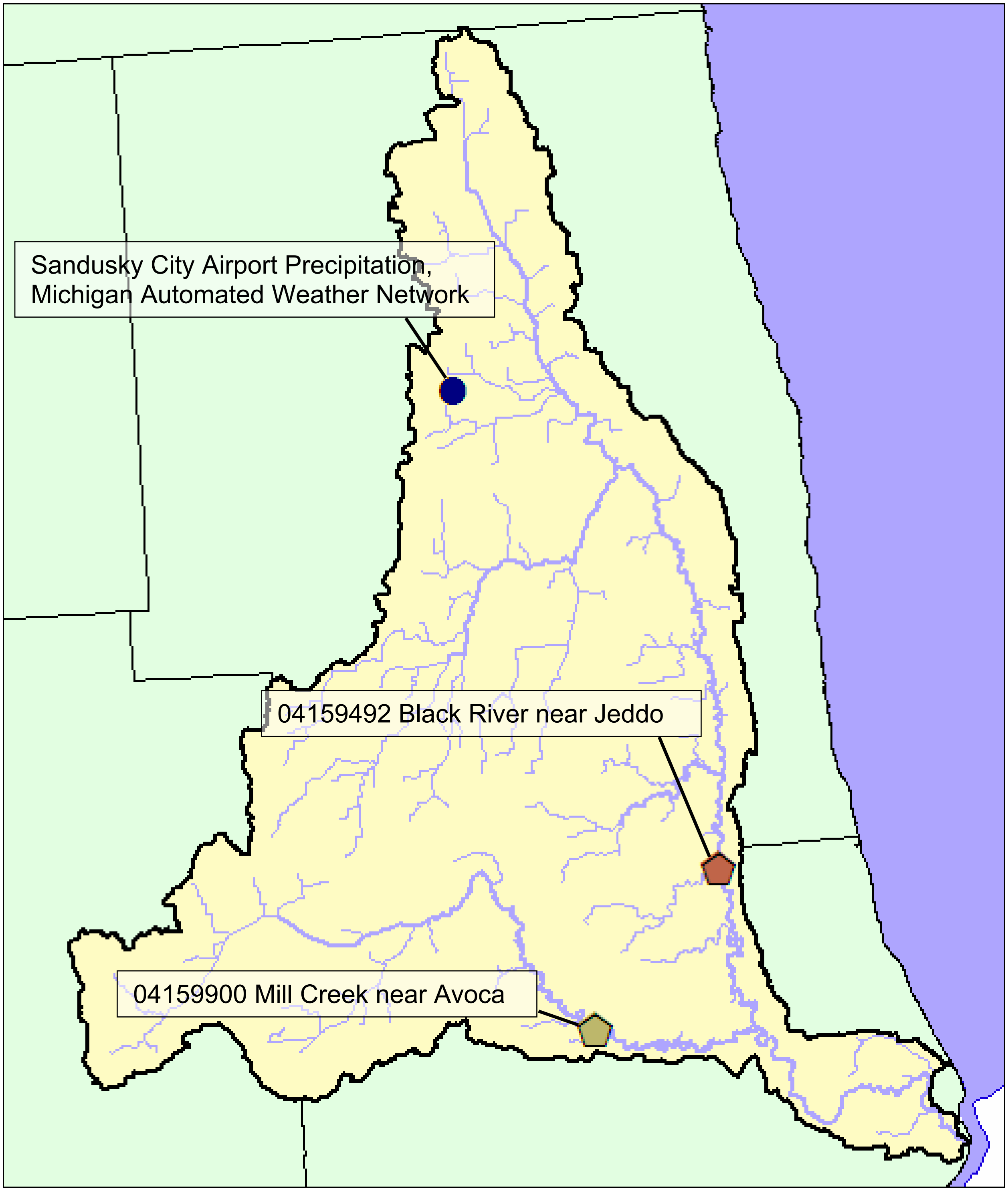


Figure 18 – Location of USGS Flow Gages and MAWN Precipitation Gage

Table 8 – Estimated Flow Recurrences Excerpted from Peak Flow Analysis of Michigan USGS Gages (Fongers, 2006)

Annual Exceedance Probability	Peak Flow Estimate (cfs)*	
	4159900, Mill Creek Near Avoca (Drainage Area: 169 square miles)	4159492, Black River Near Jeddo (Drainage Area: 462 square miles)
0.950 (1.05 years)	550	2,100
0.800 (1.25 years)	900	3,500
0.667 (1.50 years)	1,100	4,500
0.500 (2 years)	1,500	5,800
0.200 (5 years)	2,400	8,700
0.100 (10 years)	3,100	10,000
0.040 (25 years)	4,100	12,000
0.020 (50 years)	4,900	14,000
0.010 (100 years)	5,700	15,000
0.005 (200 years)	6,600	16,000
0.002 (500 years)	7,900	18,000

*HSU's flow analyses are updated regularly. Flows should be verified by HSU, www.michigan.com/deqhydrology, if used for an MDEQ permit application.

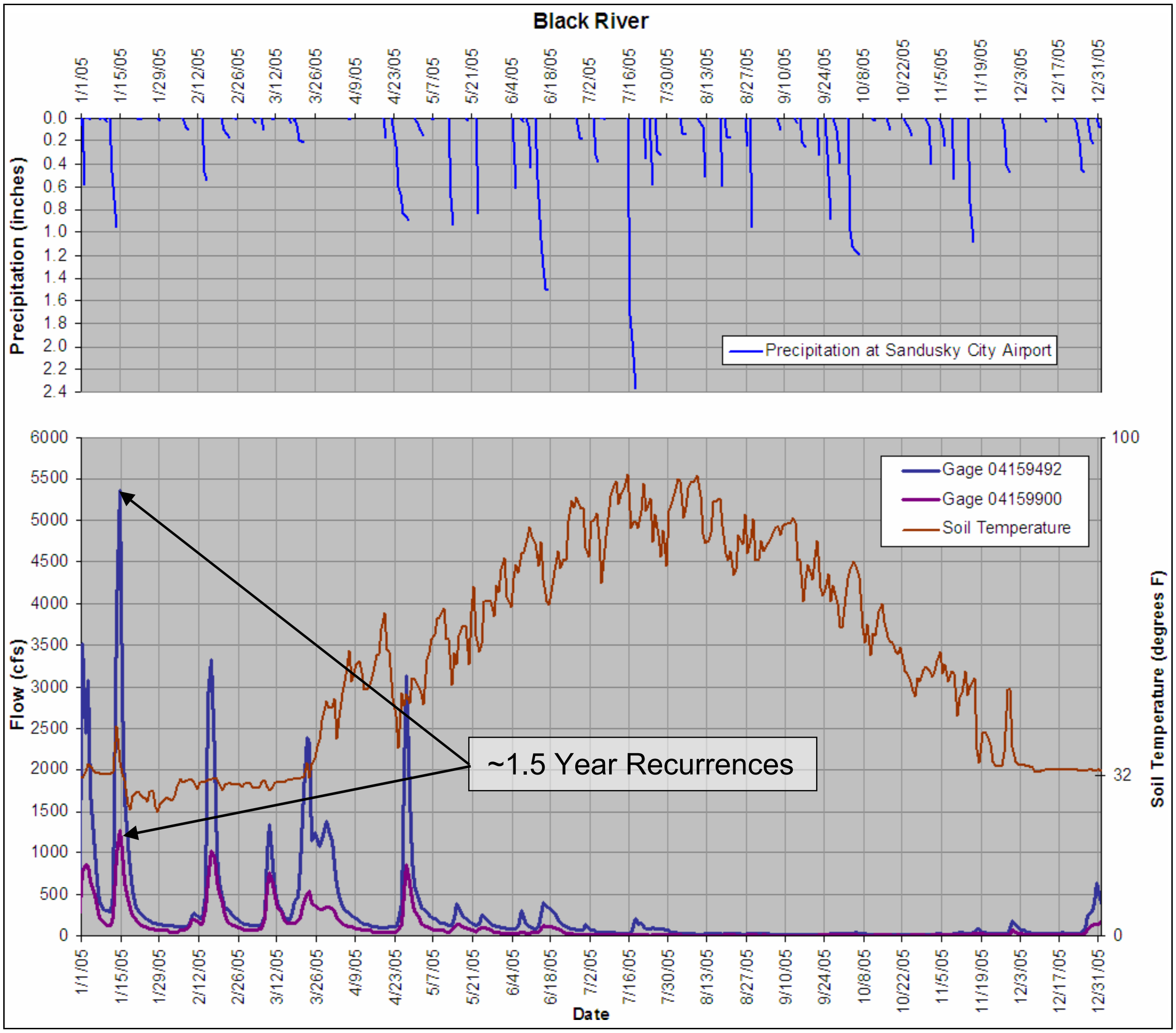


Figure 19 – Black River Hydrographs, Precipitation, and Soil Temperature for 2005

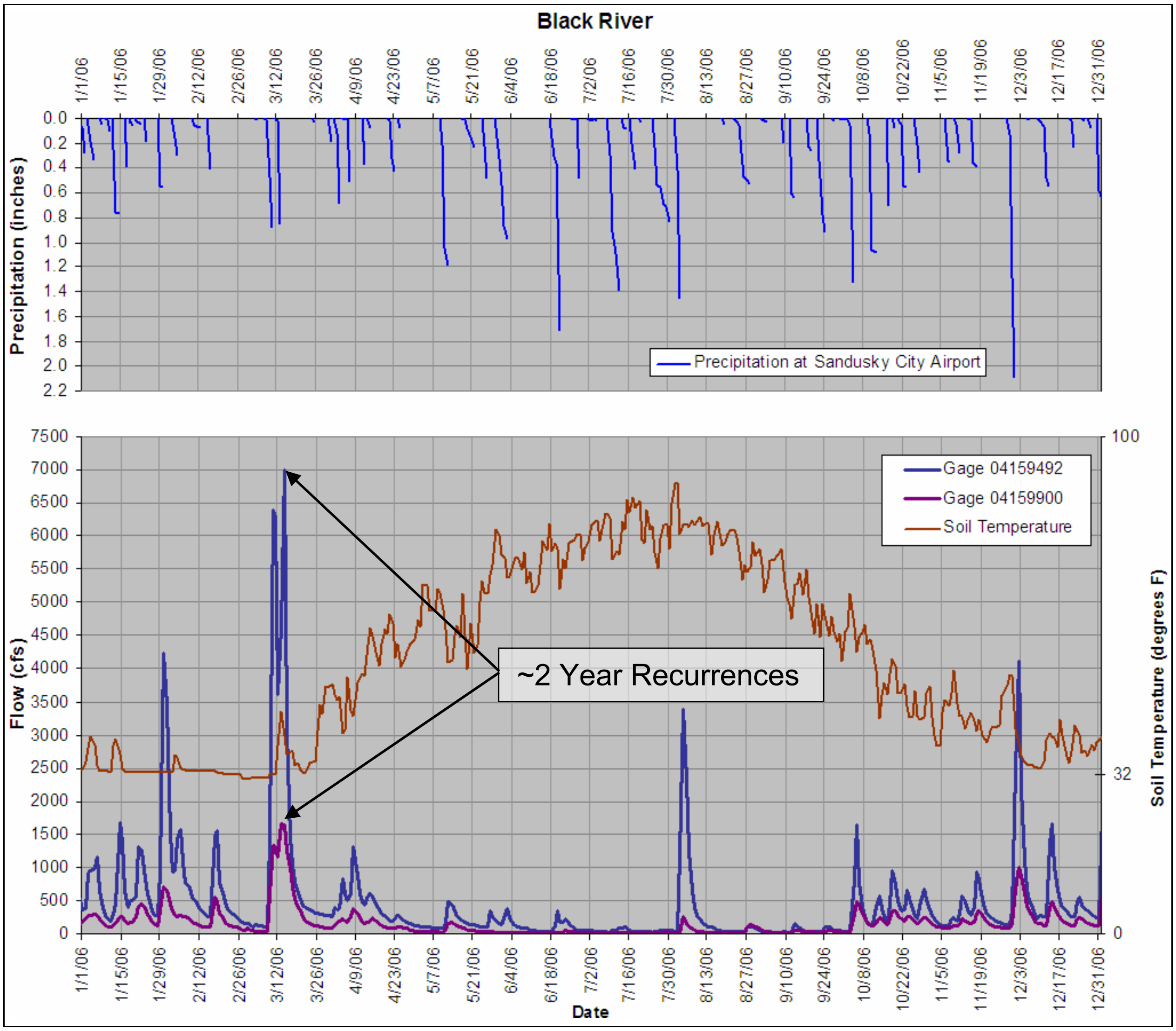


Figure 20 – Black River Hydrographs, Precipitation, and Soil Temperature for 2006

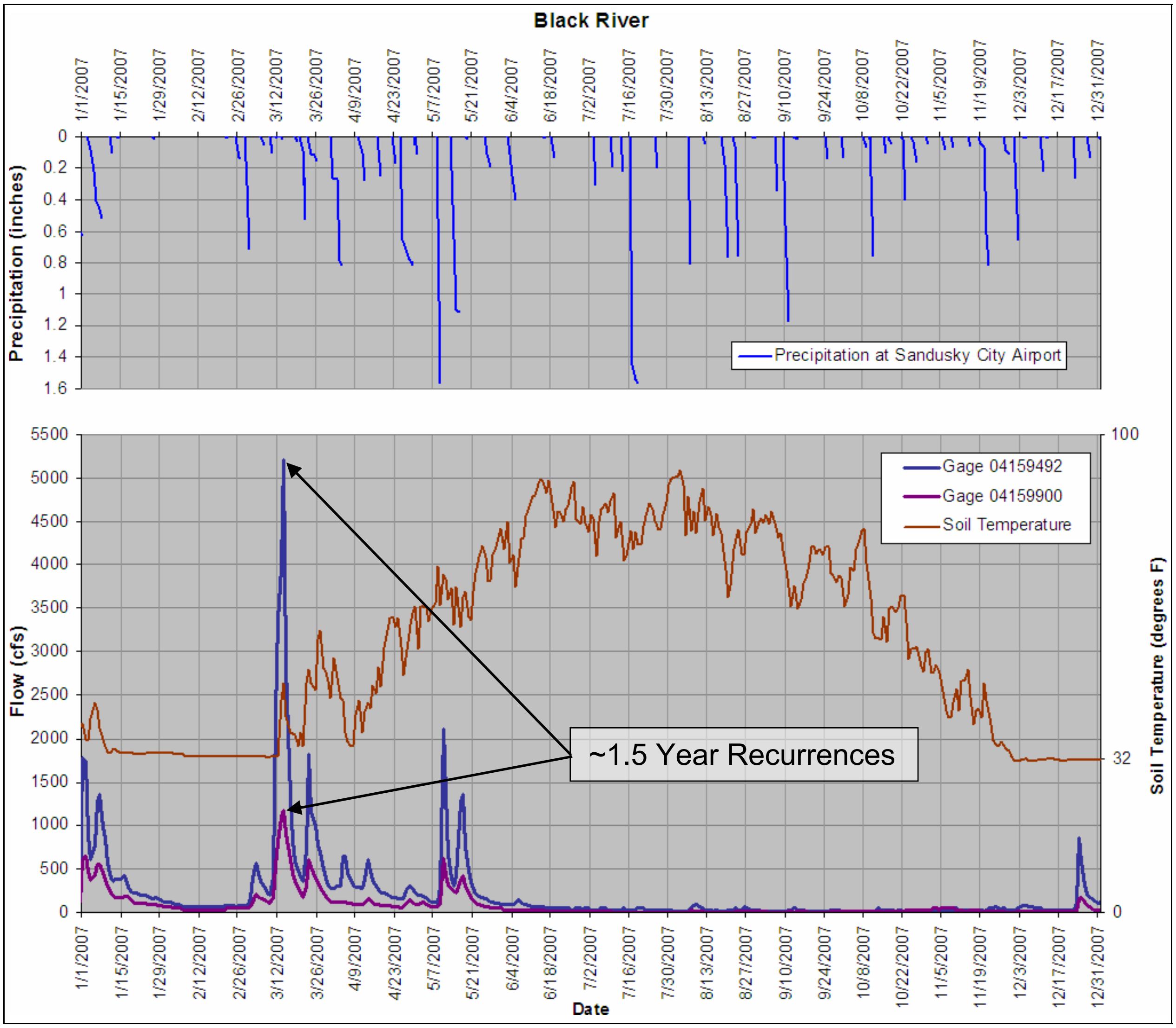


Figure 21 – Black River Hydrographs, Precipitation, and Soil Temperature for 2007

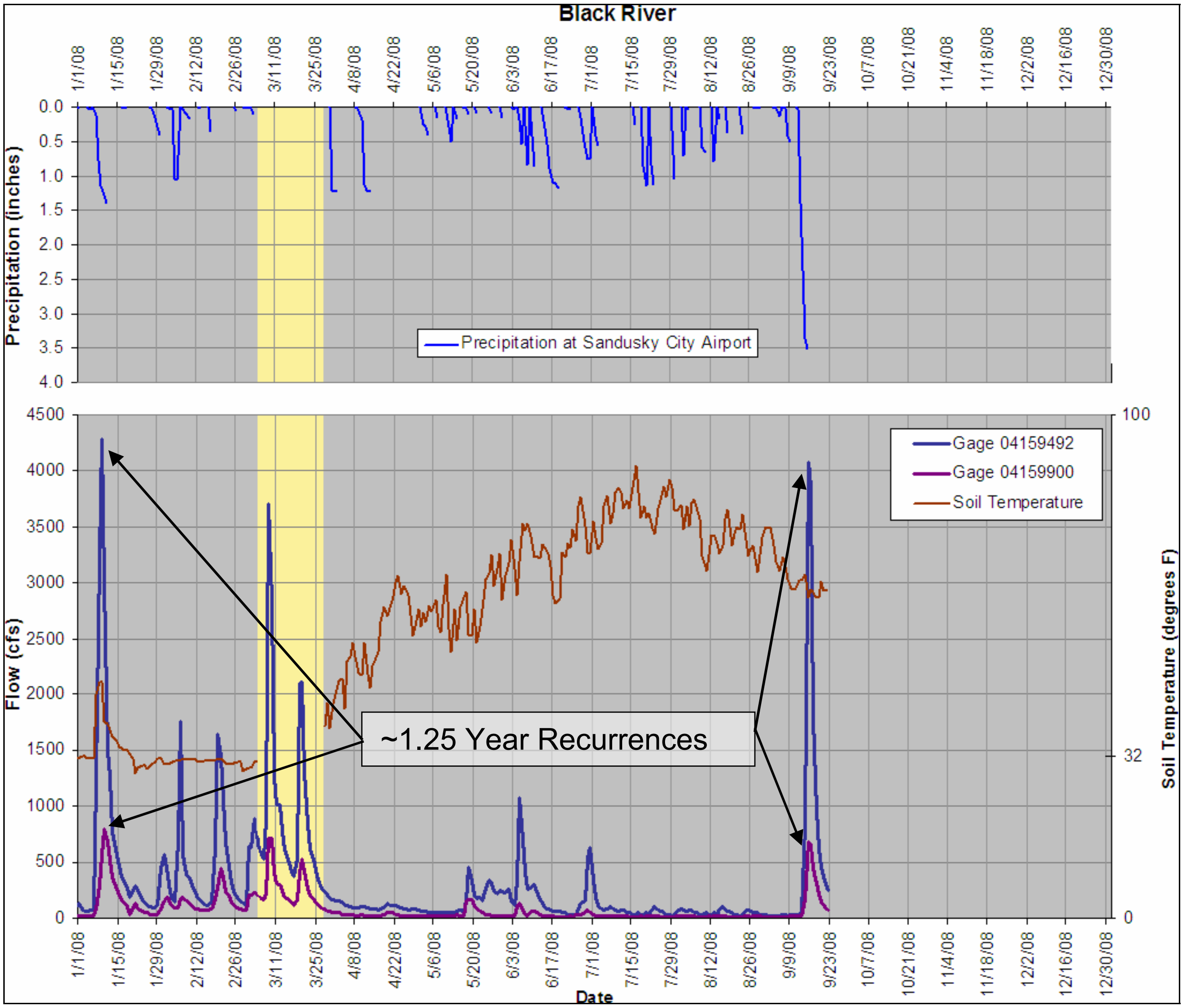


Figure 22 – Black River Hydrographs, Precipitation, and Soil Temperature for 2008
Data shown are the data available when the report was finished. Soil temperature and Rainfall data are not available for 3/5/2008 through 3/27/2008.

Time of Concentration and Storage Coefficients

Time of concentration, Tc, is the time it takes for water to travel from the hydraulically most distant point in the subbasin to the design point. Times of concentration for each subbasin were calculated using United States Geological Survey (USGS) quadrangles following the methodology described in “Computing Flood Discharges For Small Ungaged Watersheds” (Sorrell, 2008).

Storage coefficients, SC, represent temporary storage in ponds, lakes, or swampy areas in each subbasin. Storage Coefficients are initially set equal to the curve numbers then iteratively adjusted to provide a peak flow reduction equal to the ponding adjustment factors shown in Table 9 and detailed in “Computing Flood Discharges For Small Ungaged Watersheds” (Sorrell, 2008).

Table 9 – Ponding Adjustment Factors

ID	Subbasin	Ponding, 1800	Adjustment Factor, 50% Storm	Ponding, 1978	Adjustment Factor, 50% Storm
1	Black River below Darlington Drain	47.5%	0.44	5.9%	0.63
2	Black River above Bishop Drain	71.4%	0.41	24.5%	0.51
3	Black River below Pelton Drain	51.7%	0.44	0.4%	0.90
4	Berry Drain at Mouth	56.0%	0.43	0.8%	0.85
5	Black River below Berry Drain	46.0%	0.45	0.6%	0.87
6	Elk Creek below Lapee and Sanilac Drain	42.9%	0.45	0.8%	0.85
7	E. Br. Speaker and Maple Valley Dr. at Mouth	27.4%	0.50	1.5%	0.81
8	Elk Creek above McDonald Drain	36.9%	0.47	0.6%	0.87
9	McDonald Drain at Mouth	39.4%	0.46	1.0%	0.83
10	Elk Creek below Beals and Frizzle Drain	21.5%	0.52	0.1%	1.00
11	Potts Drain above Spring Creek Drain	37.0%	0.47	1.9%	0.79
12	Potts Drain at Mouth	42.6%	0.46	2.9%	0.71
13	Elk Creek at Mouth	44.5%	0.45	6.7%	0.62
14	Black River below Elk Creek	45.4%	0.45	7.8%	0.61
15	Black River below Papst Drain	17.3%	0.54	8.3%	0.60
16	Black River above Arnot Drain	14.3%	0.56	8.4%	0.60
17	Black River above Black Creek	26.5%	0.50	8.8%	0.59
18	Black Creek below Jackson Creek	15.9%	0.55	1.8%	0.79
19	Black Creek at Mouth	19.9%	0.53	8.9%	0.59
20	Silver Creek at Gage #04159488	10.3%	0.58	0.2%	0.94
21	Black River at Gage #04159492	15.1%	0.55	3.6%	0.68
22	Black River at Gage #04159500	9.8%	0.58	0.4%	0.90
23	South Branch Mill Creek below Weitzig Drain	24.5%	0.51	1.0%	0.83
24	South Branch Mill Creek below Kolb Drain	58.2%	0.43	4.2%	0.67
25	South Branch Mill Creek at Mouth	57.1%	0.43	4.5%	0.66
26	Elk Lake Creek below Brant Lake Drain	17.4%	0.54	7.6%	0.61
27	North Branch Mill Creek below Madison Drain	24.4%	0.51	3.1%	0.70
28	North Branch Mill Creek at Mouth	39.0%	0.46	1.6%	0.80
29	Mill Creek below Sanilac & St Clair Drain	16.7%	0.55	0.7%	0.86
30	Mill Creek above Sheehy Drain	26.8%	0.50	1.7%	0.80
31	Mill Creek at Gage #04159900	25.0%	0.51	0.7%	0.86
32	Mill Creek at Gage #04160000	2.0%	0.78	0.3%	0.92
33	Black River at Gage #04160050	2.5%	0.73	1.3%	0.82
34	Black River at Mouth	21.7%	0.52	2.5%	0.73

Results

Runoff Volume per Area Analysis

Runoff volumes were calculated for each subbasin from 1800 to 1978 for the 50 percent chance (2-year), 24-hour storm. For comparison, the calculated runoff volumes are divided by the drainage areas. Three subbasins had decreases and the remaining 31 subbasins have increases of up to 100 percent. The results are shown in Figures 23 and 24 and tabulated in Table10. The units are acre-inches per acre (volume per area), or simply inches. Changes in runoff volume per area from 1800 to 1978 are shown in Figure 25 and are also tabulated in Table 10.

The results highlight subbasins that generate a higher proportion of runoff due to soils and land use. Either current runoff volume per area or runoff volume change per area can be used to help select critical areas. Higher values can identify areas that may need rehabilitation activities. Lower values can identify sensitive areas to be protected. The 1800 scenario is included to show the impact of land use change, but is not intended as BMP design criteria or as a goal for watershed managers.

In terms of total volume, the watershed would have generated 13,600 acre-feet of runoff from a 2.2 inch rainfall in 1800. In 1978, it would have generated 17,700 acre-feet, an increase of 4,100 acre-feet or 30 percent. The increased channel-forming flow runoff volume, and likely peak flow, has undoubtedly resulted in channel enlargement as the Black River and its tributaries adapt to the higher flows.

Future hydrologic changes can further impact stream flows, water quality, channel erosion, and flooding. These changes can be moderated with effective stormwater management techniques such as:

- treatment of the “first flush” runoff
- wetland protection
- retention and infiltration of excess runoff
- low impact development techniques
- 24-hour extended detention of 1-year flows
- properly designed detention of runoff from low probability storms

Refer to the Stream Morphology and Stormwater Management sections for more detail.

Table 10 – Runoff Volume per Area by Subbasin

ID	Subbasin	Runoff Volume/Area (inch)		
		1800	1978	Change
1	Black River below Darlington Drain	0.34	0.28	-0.06
2	Black River above Bishop Drain	0.37	0.39	0.02
3	Black River below Pelton Drain	0.40	0.52	0.12
4	Berry Drain at Mouth	0.51	0.18	-0.33
5	Black River below Berry Drain	0.41	0.50	0.09
6	Elk Creek below Lapee and Sanilac Drain	0.50	0.58	0.08
7	East Branch Speaker and Maple Valley Drain at Mouth	0.43	0.57	0.14
8	Elk Creek above McDonald Drain	0.40	0.54	0.14
9	McDonald Drain at Mouth	0.38	0.50	0.12
10	Elk Creek below Beals and Frizzle Drain	0.46	0.56	0.10
11	Potts Drain above Spring Creek Drain	0.45	0.56	0.11
12	Potts Drain at Mouth	0.34	0.43	0.09
13	Elk Creek at Mouth	0.34	0.41	0.07
14	Black River below Elk Creek	0.37	0.27	-0.10
15	Black River below Papst Drain	0.23	0.41	0.18
16	Black River above Arnot Drain	0.20	0.40	0.20
17	Black River above Black Creek	0.27	0.42	0.15
18	Black Creek below Jackson Creek	0.41	0.58	0.17
19	Black Creek at Mouth	0.43	0.58	0.15
20	Silver Creek at Gage #04159488	0.46	0.72	0.26
21	Black River at Gage #04159492	0.31	0.42	0.11
22	Black River at Gage #04159500	0.32	0.53	0.21
23	South Branch Mill Creek below Weitzig Drain	0.47	0.73	0.26
24	South Branch Mill Creek below Kolb Drain	0.48	0.61	0.13
25	South Branch Mill Creek at Mouth	0.32	0.46	0.14
26	Elk Lake Creek below Brant Lake Drain	0.25	0.43	0.18
27	North Branch Mill Creek below Madison Drain	0.24	0.30	0.06
28	North Branch Mill Creek at Mouth	0.36	0.50	0.14
29	Mill Creek below Sanilac & St Clair Drain	0.35	0.54	0.19
30	Mill Creek above Sheehy Drain	0.32	0.52	0.20
31	Mill Creek at Gage #04159900	0.39	0.58	0.19
32	Mill Creek at Gage #04160000	0.31	0.53	0.22
33	Black River at Gage #04160050	0.13	0.20	0.07
34	Black River at Mouth	0.24	0.40	0.16

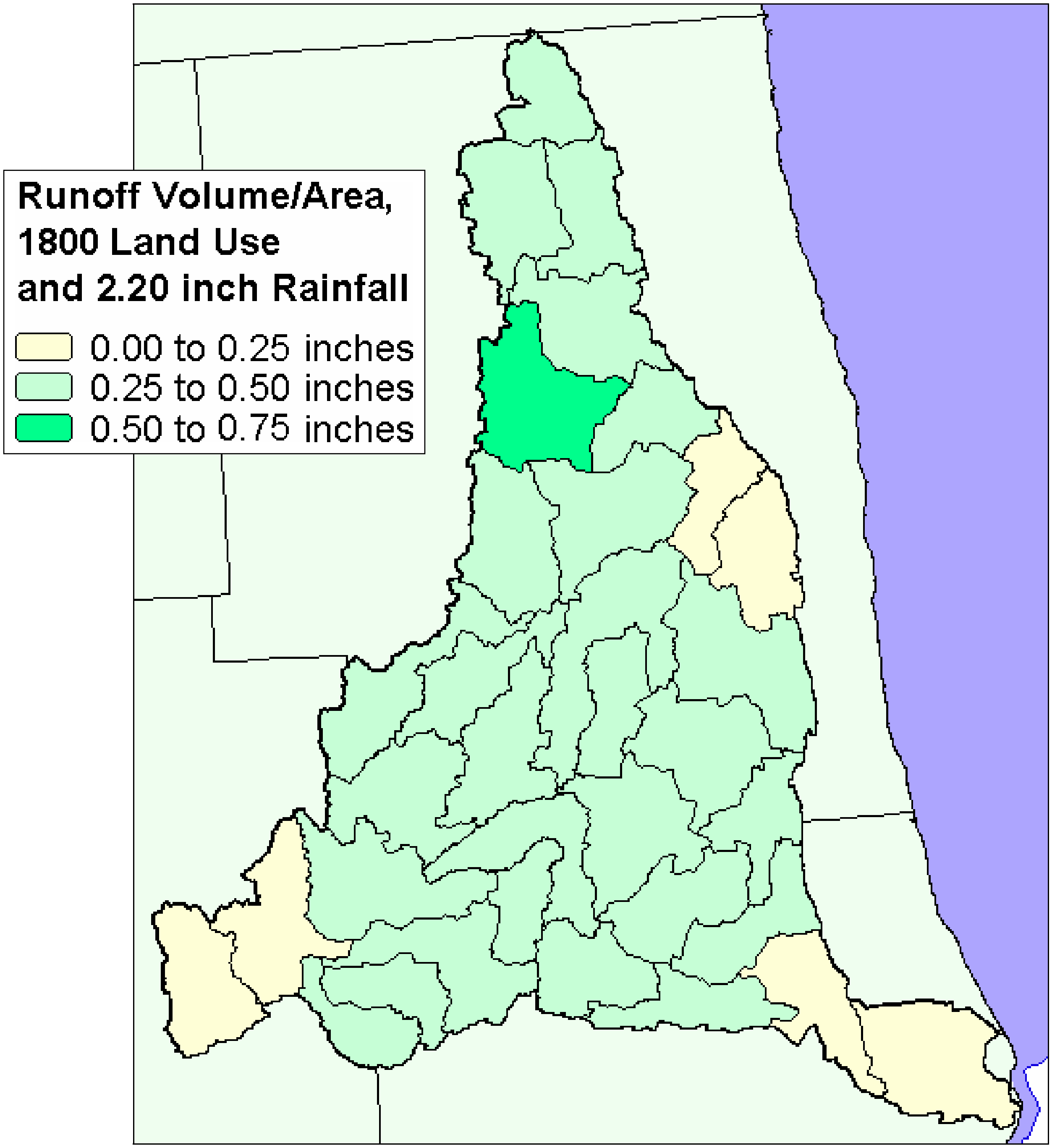


Figure 23 – Runoff Volume/Drainage Area, 1800 Land Use

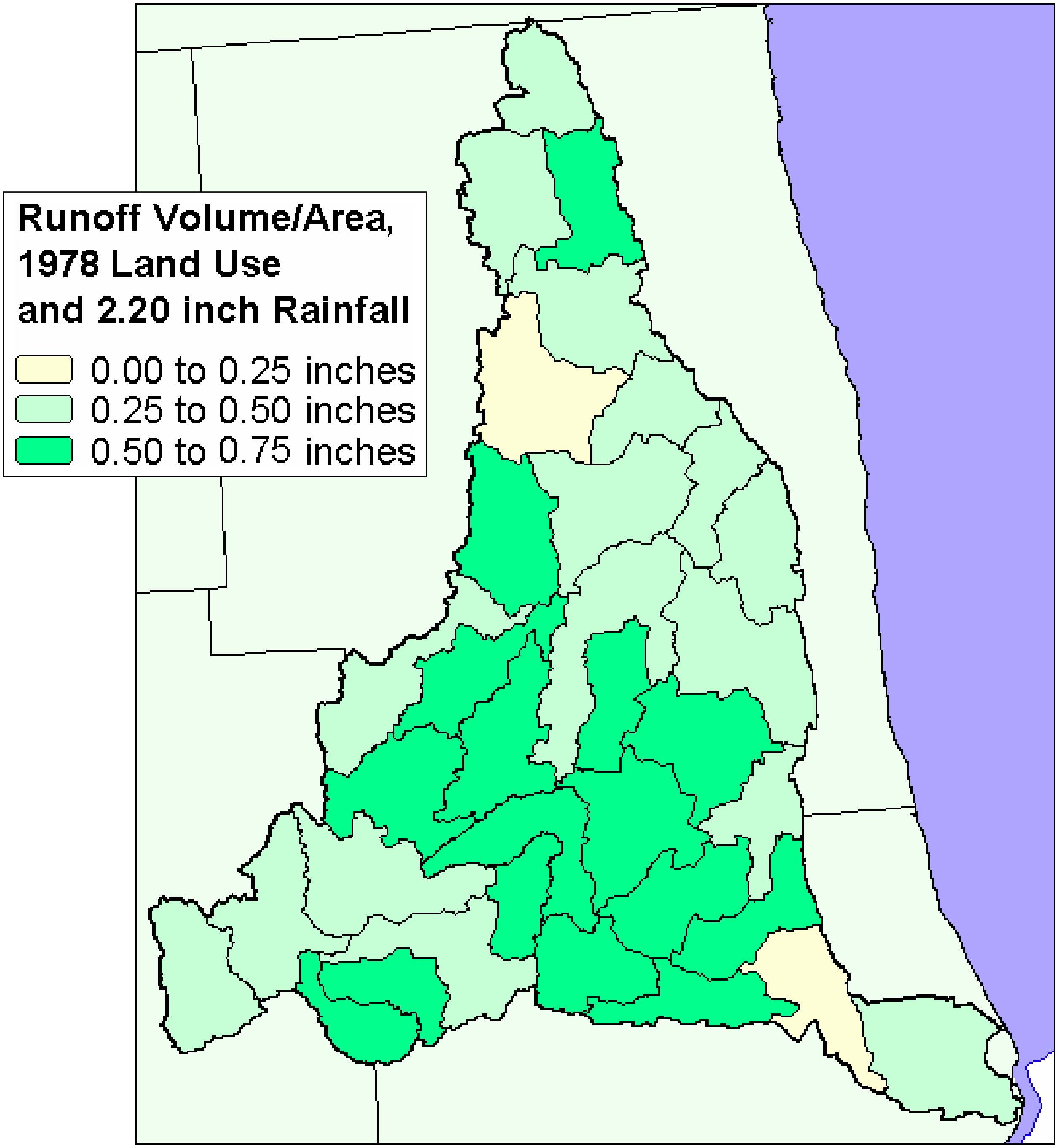


Figure 24 – Runoff Volume/Drainage Area, 1978 Land Use

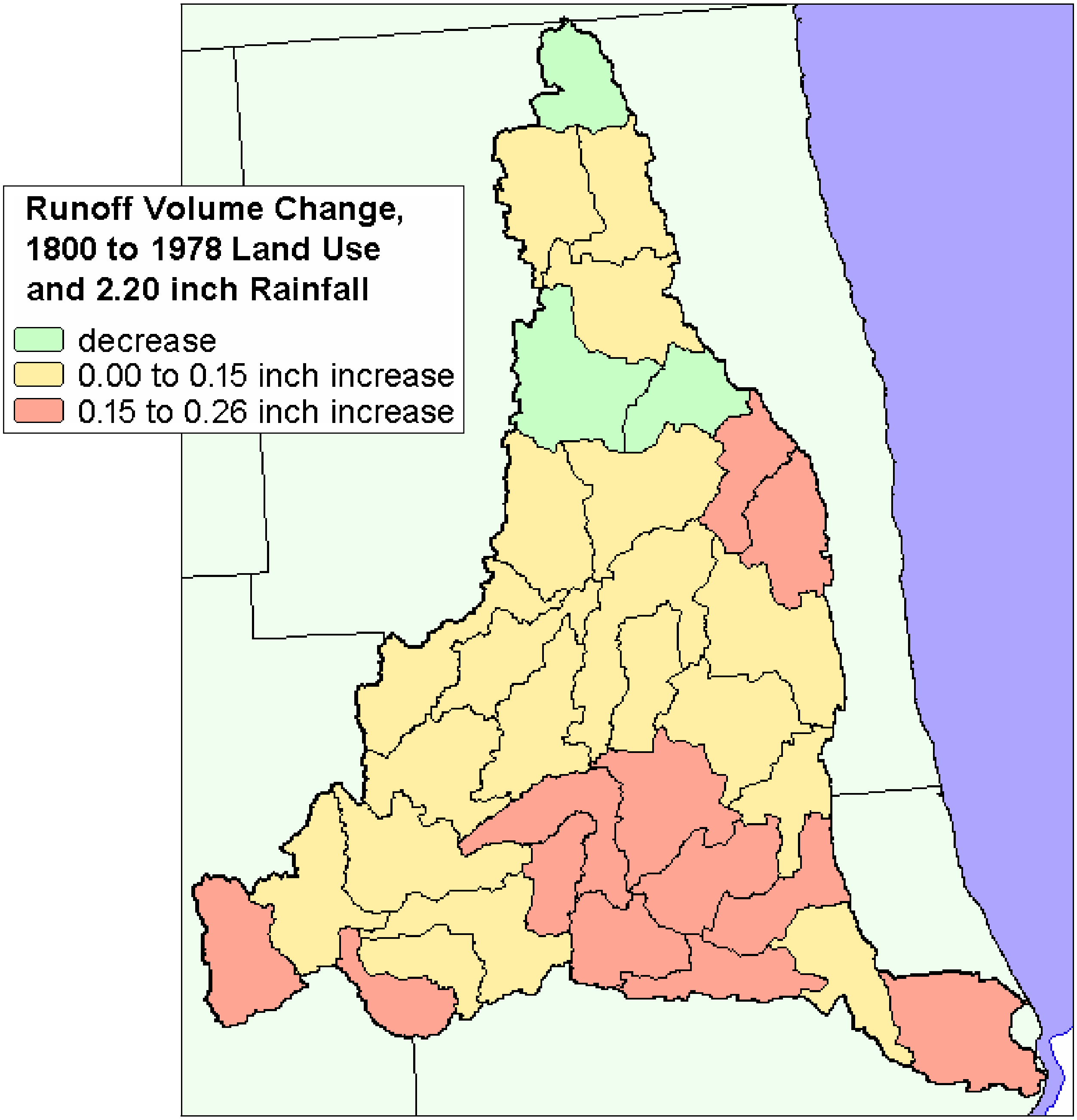


Figure 25 – Change in Runoff Volume/Drainage Area, 1800 to 1978 Land Use

Peak Flood Flow Yield Analysis

The preceding runoff analysis accounts only for land use and soils. Peak flood flow yield analysis adds runoff storage, or ponding, and the time it takes for runoff to flow through the subbasin's drainage network. Peak flood flow yield, which is the peak flow divided by the drainage area, is therefore a more complete measure of the hydrologic responsiveness of each subbasin. Peak flood flow yields are intended to provide a measure of relative subbasin hydrologic responsiveness. They cannot be used to calculate peak flows for any portion of a subbasin.

To ensure that yield values are comparable, subbasins are similarly sized, and a confidence range is provided based on the drainage area ratio equation used by MDEQ's Hydrologic Studies Unit. The equation is $Q_2 = Q_1*(A_2/A_1)^{0.89}$. The confidence range adjusts each yield based on the smallest and largest subbasins in the study.

Graphs of the peak flood flow yields and confidence intervals for each subbasin for the 1800 and 1978 scenarios are shown in Figure 26. Figures 27 and 28 are maps of the same data using a consistent legend, in cfs/acre, to group the data.

A higher peak flood flow yield indicates that the subbasin has comparatively more runoff due to the combination of soils, land uses, stormwater storage, and drainage efficiency, and is contributing a proportionately higher flow to the receiving streams.

Peak flood flow yield changes from 1800 to 1978 are shown in Figure 29 and tabulated in Table 11. As with the runoff analysis, even though the results are based on one specific storm, the overall trends would be similar for larger storms also. Since both scenarios use the same time of concentration values, changes in peak flood flow yields do not reflect any changes in drainage efficiency that may have occurred.

Either peak flood flow yields or runoff volume per area can be used to help select critical areas. Lower values can identify sensitive areas to be protected. Higher values can identify areas that need rehabilitation activities.

Table 11 – Peak Flood Flow Yield by Subbasin

ID	Subbasin	Peak Flood Flow Yield (cfs/acre)*		
		1800	1978	Change
1	Black River below Darlington Drain	0.005	0.006	15%
2	Black River above Bishop Drain	0.003	0.004	21%
3	Black River below Pelton Drain	0.006	0.015	157%
4	Berry Drain at Mouth	0.005	0.003	-39%
5	Black River below Berry Drain	0.005	0.011	120%
6	Elk Creek below Lapee and Sanilac Drain	0.007	0.015	109%
7	East Branch Speaker and Maple Valley Drain at Mouth	0.005	0.010	101%
8	Elk Creek above McDonald Drain	0.005	0.011	130%
9	McDonald Drain at Mouth	0.003	0.007	95%
10	Elk Creek below Beals and Frizzle Drain	0.006	0.014	123%
11	Potts Drain above Spring Creek Drain	0.006	0.013	101%
12	Potts Drain at Mouth	0.003	0.005	69%
13	Elk Creek at Mouth	0.003	0.004	43%
14	Black River below Elk Creek	0.004	0.004	-7%
15	Black River below Papst Drain	0.005	0.009	101%
16	Black River above Arnot Drain	0.002	0.004	109%
17	Black River above Black Creek	0.002	0.004	68%
18	Black Creek below Jackson Creek	0.008	0.017	107%
19	Black Creek at Mouth	0.006	0.009	50%
20	Silver Creek at Gage #04159488	0.007	0.018	152%
21	Black River at Gage #04159492	0.007	0.012	69%
22	Black River at Gage #04159500	0.005	0.011	151%
23	South Branch Mill Creek below Weitzig Drain	0.008	0.020	155%
24	South Branch Mill Creek below Kolb Drain	0.005	0.009	82%
25	South Branch Mill Creek at Mouth	0.002	0.004	73%
26	Elk Lake Creek below Brant Lake Drain	0.006	0.011	98%
27	North Branch Mill Creek below Madison Drain	0.004	0.006	70%
28	North Branch Mill Creek at Mouth	0.003	0.007	103%
29	Mill Creek below Sanilac & St Clair Drain	0.004	0.009	123%
30	Mill Creek above Sheehy Drain	0.003	0.007	124%
31	Mill Creek at Gage #04159900	0.005	0.012	135%
32	Mill Creek at Gage #04160000	0.005	0.010	101%
33	Black River at Gage #04160050	0.001	0.002	63%
34	Black River at Mouth	0.002	0.004	101%

*Peak flood flow yields cannot be used to calculate peak flows for any portion of a subbasin.

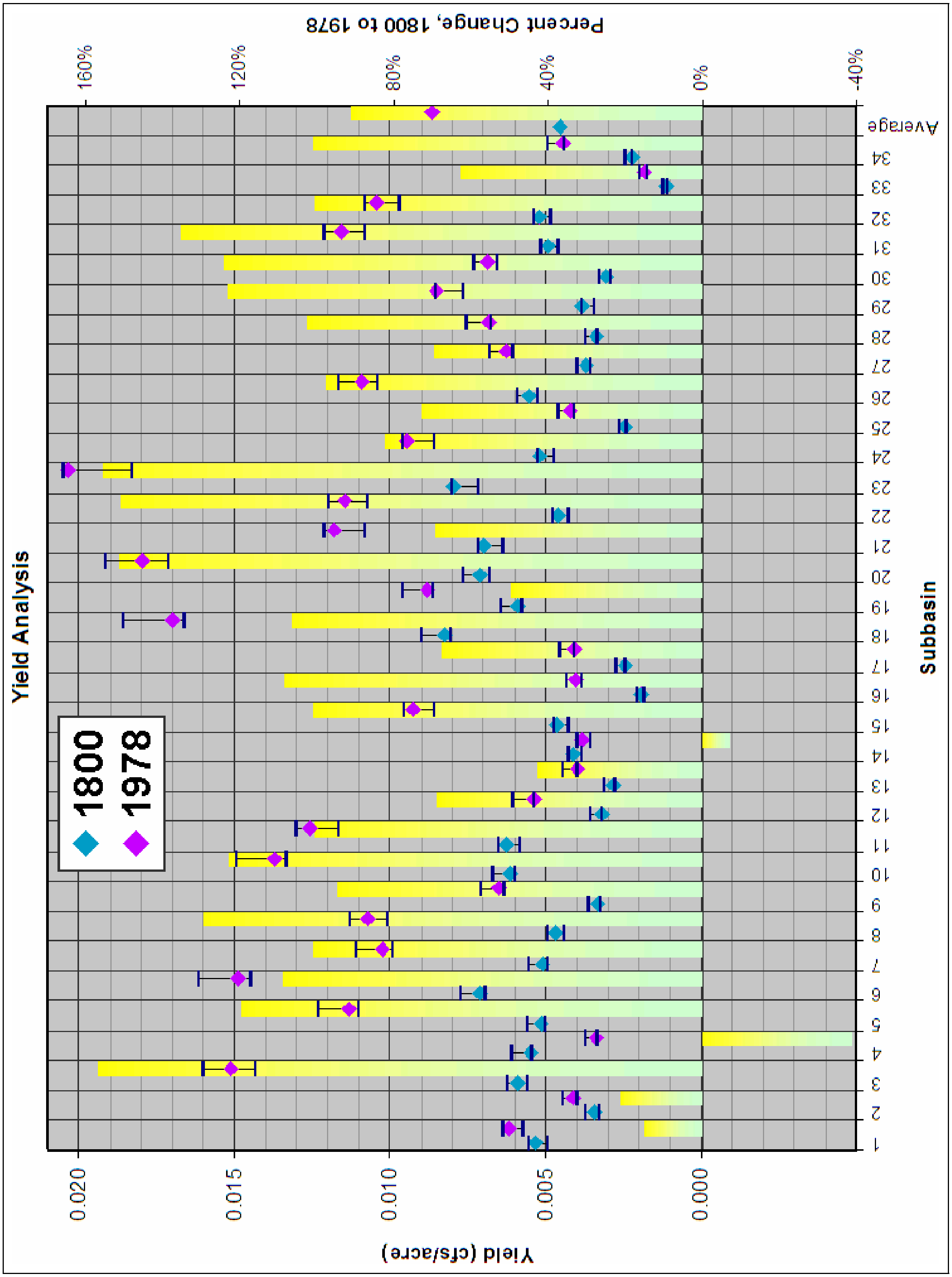


Figure 26: Peak Flood Flow Yield Analysis Chart per subbasin, with percent change from 1800 to 1978

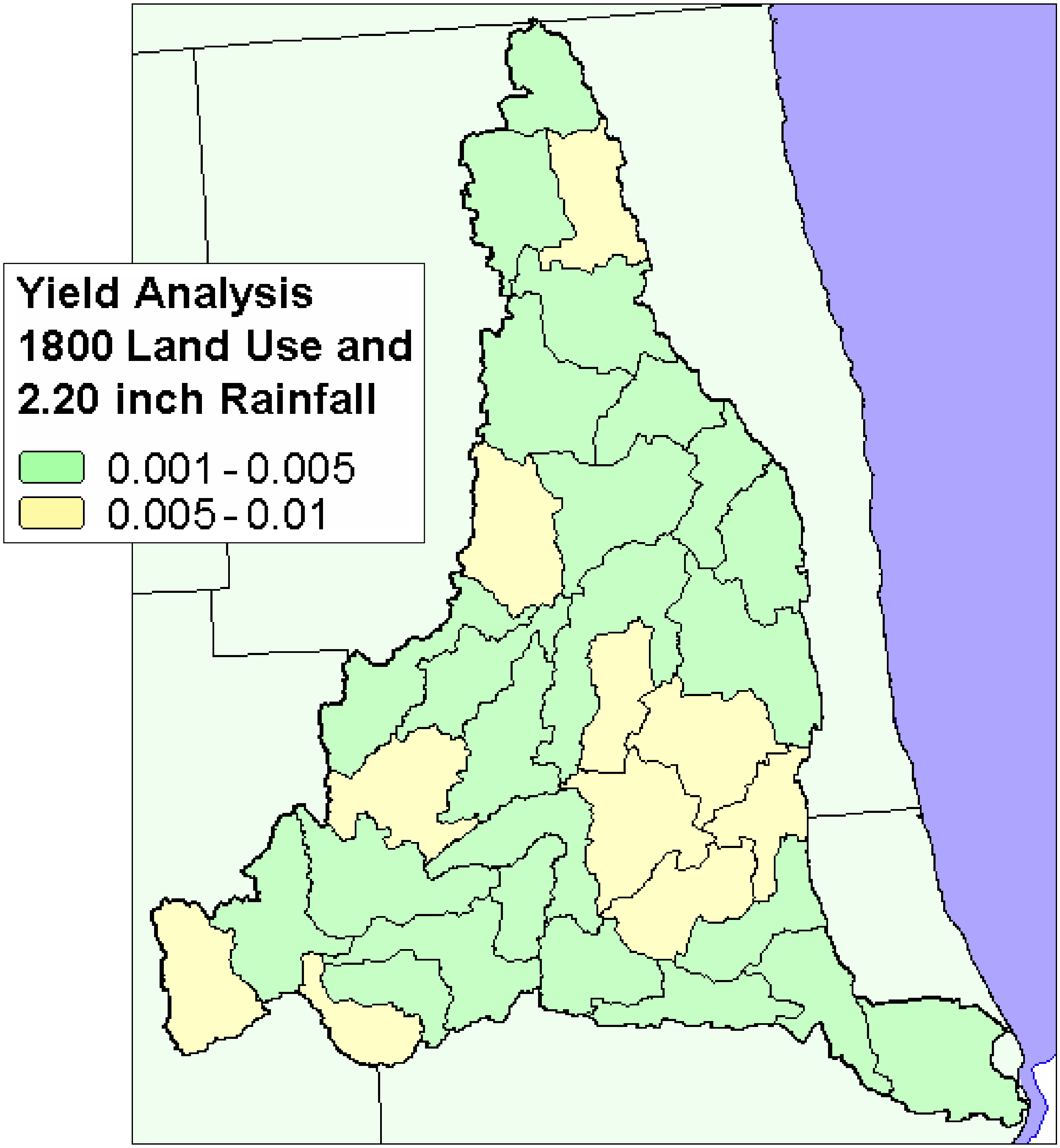


Figure 27: Peak Flood Flow Yield Analysis Map, 1800 Land Use

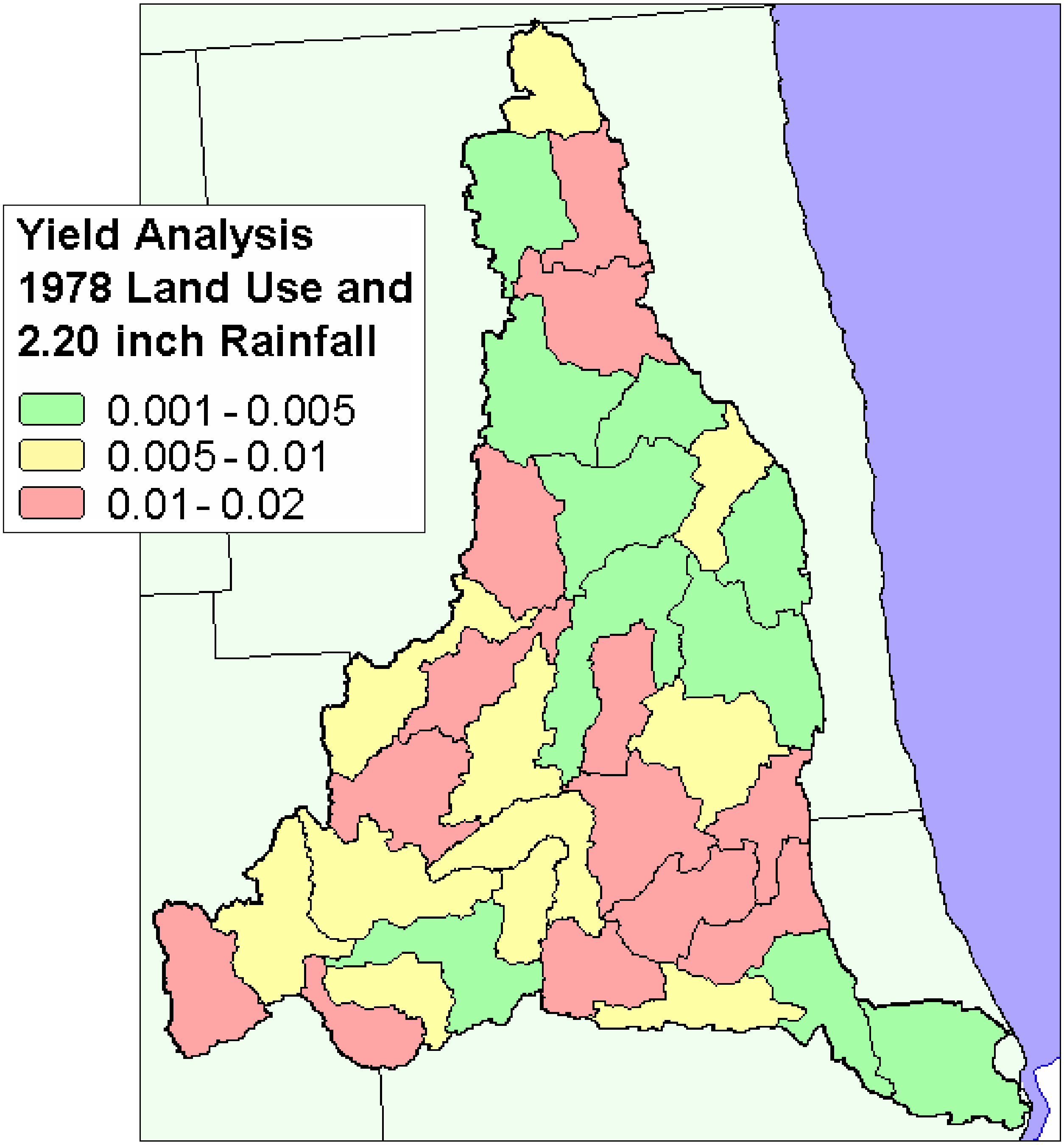


Figure 28: Peak Flood Flow Yields Analysis Map, 1978 Land Use

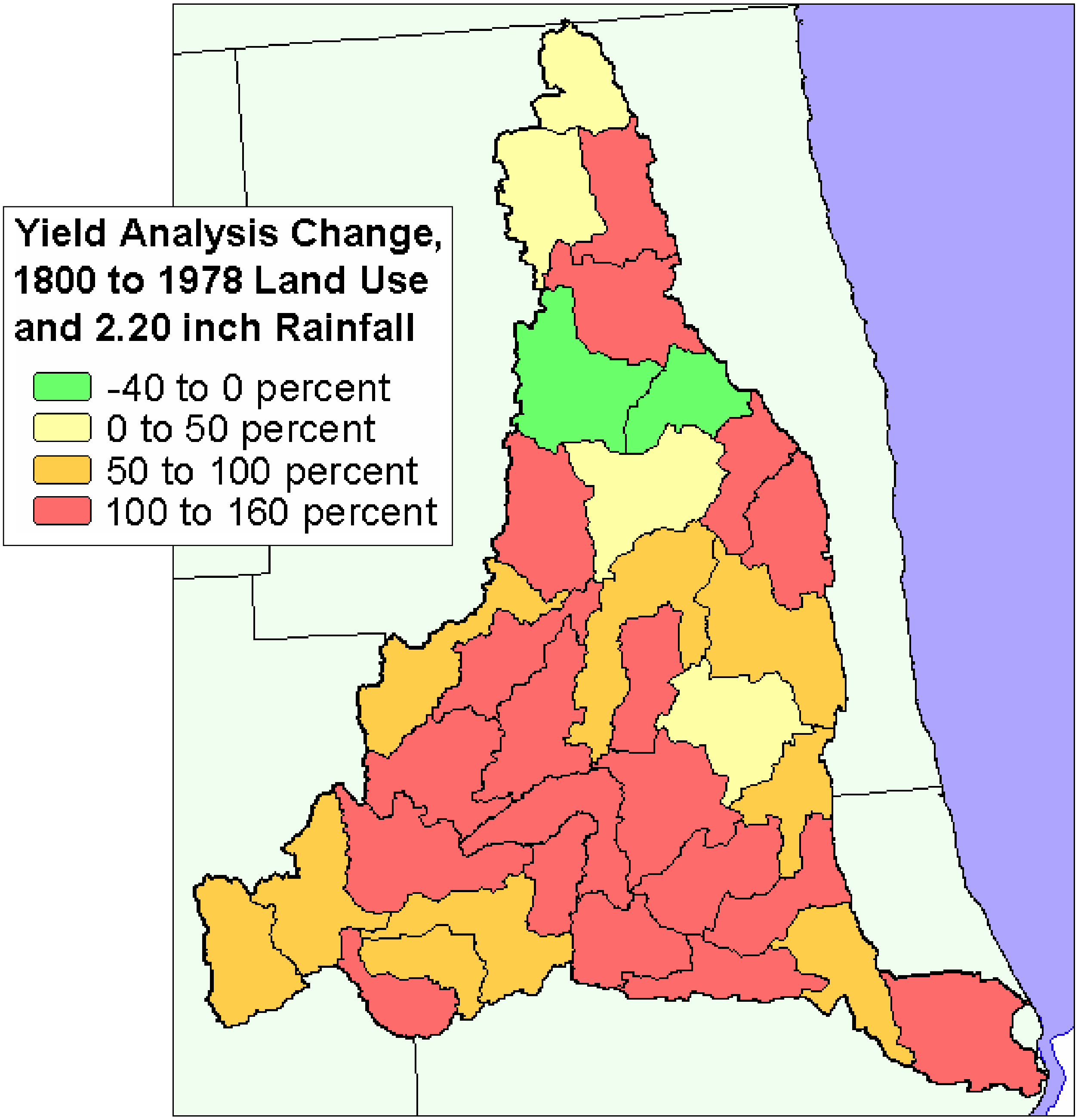


Figure 29: Peak Flood Flow Yields Analysis Map, 1800 to 1978 Land Use

Flashiness

The term flashiness reflects the frequency and rapidity of short term changes in stream flow (Baker et al, 2004). A stream described as flashy responds to rainfall by rising and falling quickly. Conversely, a stream that is not flashy would rise and fall less for an equivalent rainfall and would typically derive more of its overall flow from groundwater. An increase in flashiness is a common cause of stream channel instability. In general, flashiness changes result from hydrologic alterations. Some factors that can alter flashiness include:

- In-Stream Changes
  - Removal or change in operation of a dam
  - Expansion or straightening of the drainage network
- Watershed Land Use Changes
  - Urbanization
  - Forest regrowth
  - Soil compaction
  - Change in paved or other impervious areas
  - Use of low impact development (LID) techniques
  - Change in forestry practices
  - Change in agricultural practices
  - Change in runoff storage capacity

One approach to quantifying flashiness was proposed by Baker et al (2004). The method measures the path length of flow oscillations for data from gaged streams. Longer paths correlate with flashier streams, while more constant flows have shorter path lengths. Values for the R-B Index could theoretically range from zero to two. It would have a value of zero if the stream flow were absolutely constant. Its value increases as the path length, and therefore flashiness, increases. The Lower Rouge River hydrograph, Figure 30, illustrates the longer flow path associated with a flashy stream. The Au Sable River hydrograph illustrates the shorter flow path associated with more constant flows.

The R-B Index is one tool for diagnosing the scale of a particular stream channel problem. If the R-B Index values are steady over time, channel erosion problems in the vicinity of the USGS gage may have local, small-scale causes (e.g., cattle access) that can be addressed with a local BMP (e.g., fencing). Conversely, if the R-B Index trend indicates that flashiness is increasing over time, channel erosion problems in the vicinity of the gage station may have large scale causes (e.g., a watershed-wide increase in impervious area) and will require a large scale solution (e.g., regional stormwater management practices). Note that “in the vicinity of the gage” is not well defined. Streams that are increasingly flashy at one location may become stable downstream due to attenuation of flashy flows by tributary flows downstream of the gage. Similarly, flashy flows in a stream above the gage may be masked by the combined flows of other streams at the gage.

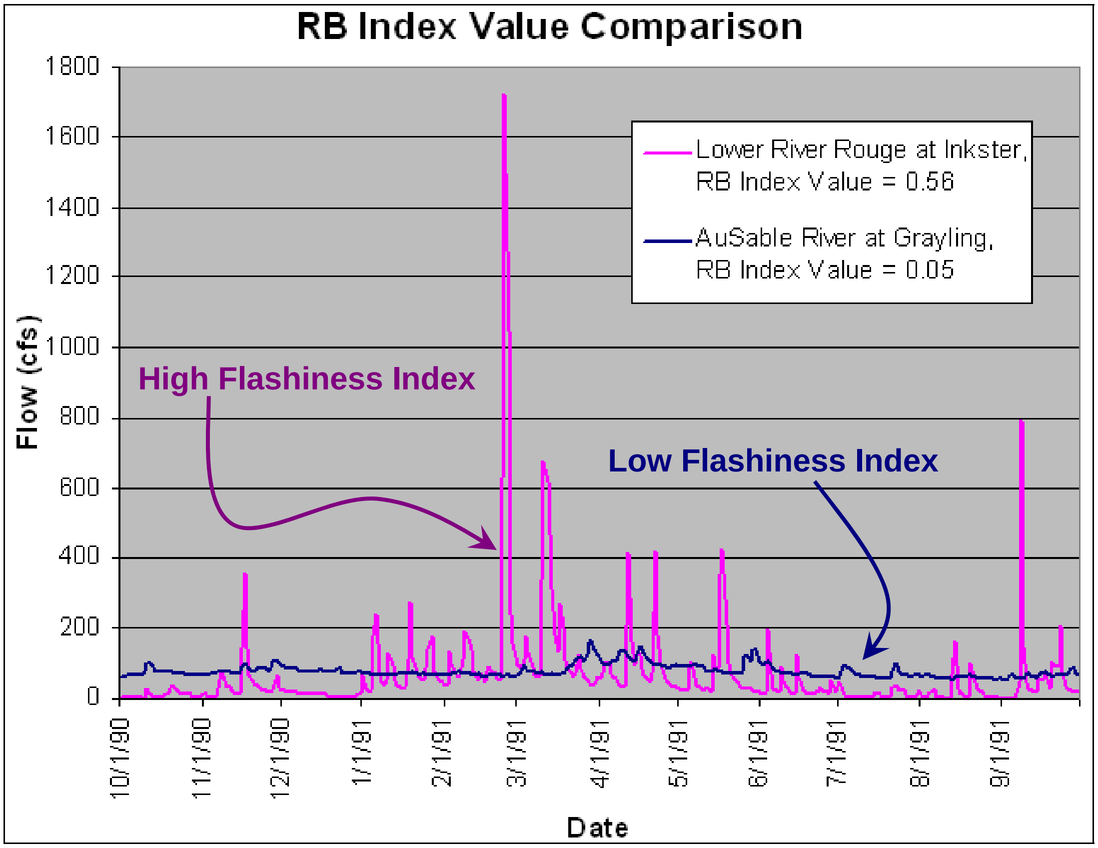


Figure 30 – Hydrographs for Two Michigan Streams

Quartile Ranking

MDEQ's NPS staff calculated yearly averaged R-B Index values and assessed trends for 279 USGS gages in Michigan that had at least five years of data through the end of water year 2004 (Fongers, 2007). The R-B Index values for Michigan ranged from 0.006 to 1.009, Figure 31. Quartile rankings are grouped by watershed size because of the natural tendency for flashiness to decrease as the drainage area increases. As watershed size increases, the varied timing of tributary flows help attenuate main channel peak flow and soils and land uses tend to diversify.

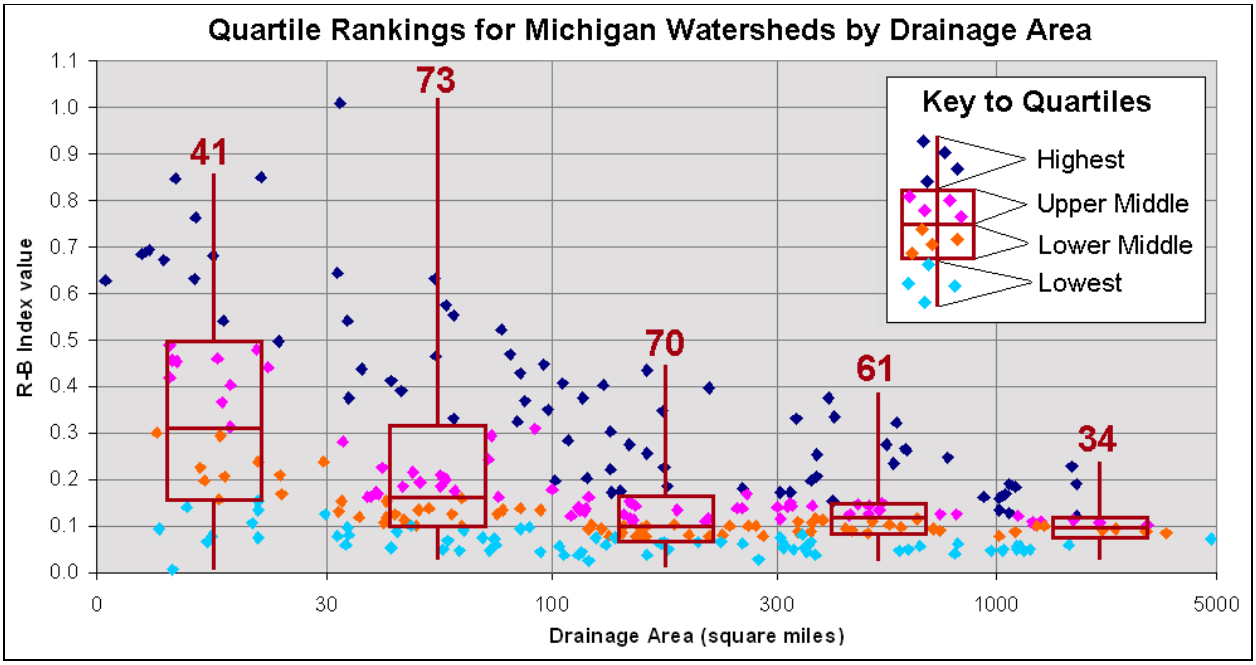


Figure 31 – Summary and Ranking of the R-B Index Values for 279 Michigan Gages

The yearly averaged R-B Index values for the Black River watershed range from 0.255 to 0.376, with every gage in the uppermost quartile on a statewide basis. In itself, a high or low ranking is not necessarily good or bad. For example, rankings for Saginaw Bay area gages tend to be high at least partly because of the soils in that area. The gage rankings in the Black River watershed are typical of other gages in the thumb area of Michigan, Figure 32, which generally are in the upper half of the rankings. The relative rankings of Black River watershed gages, Figure 33 and Table 12, may be used to identify areas where methods to reduce flashiness can be employed, or to identify areas where extra effort is warranted to protect our most sensitive and exceptional streams.

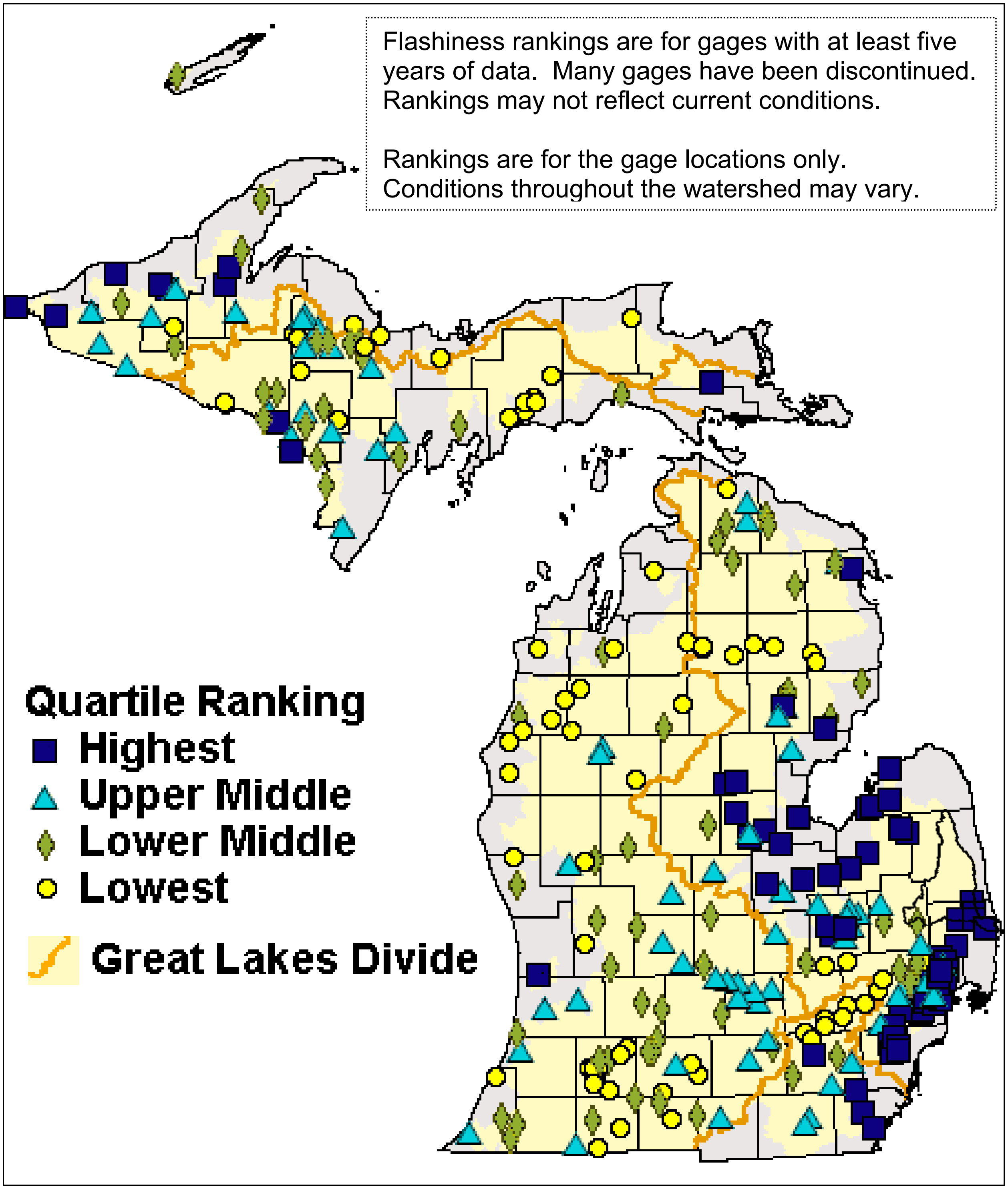


Figure 32 – Quartile Rankings, Michigan Watersheds

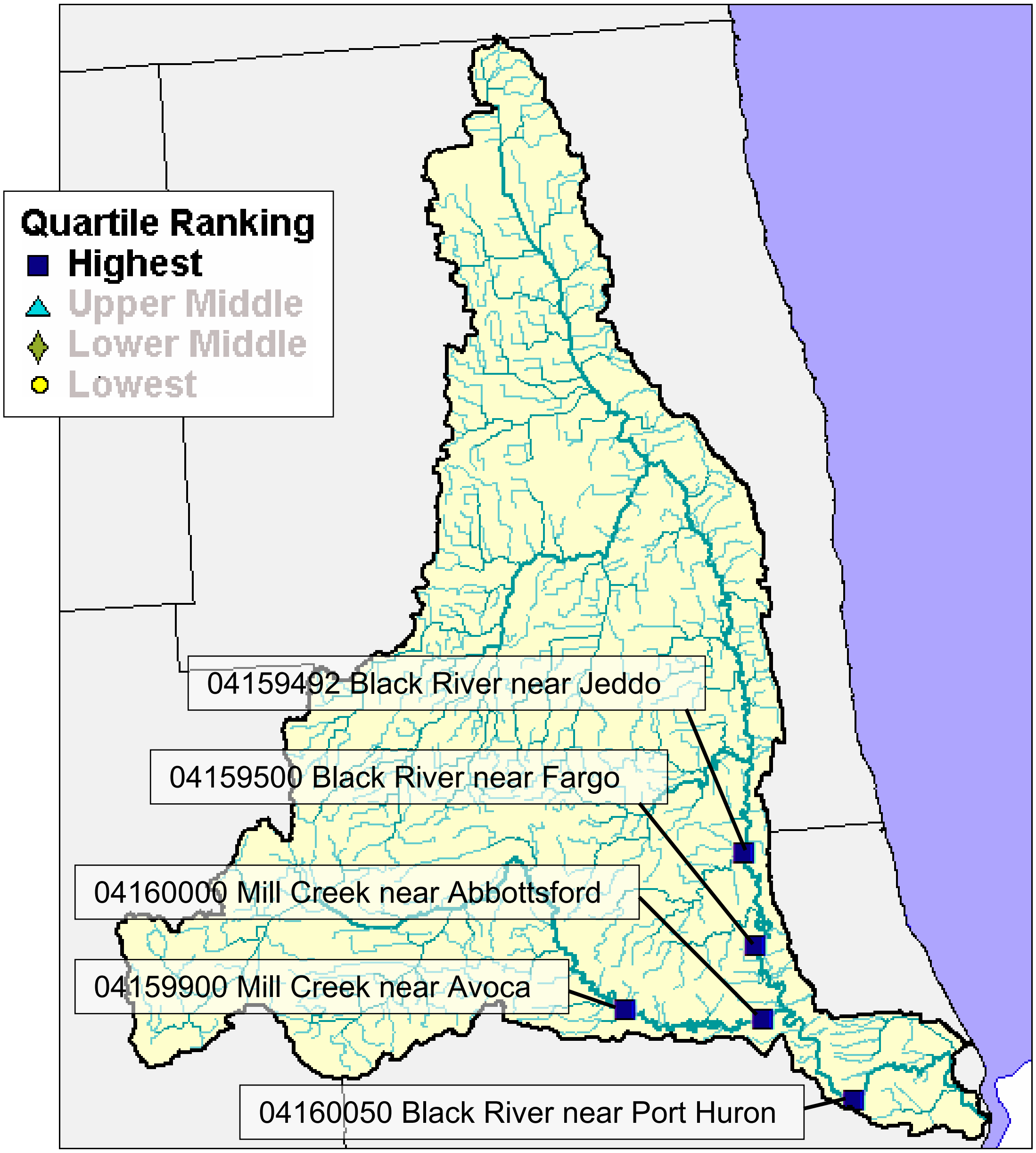


Figure 33 – Quartile Rankings, Black River Watershed

Table 12 – Black River Watershed Flashiness Results

Gage Number and Description	Total Drainage Area (sq. mi.)	Quartile Rank	Flashiness Trend
04159492 Black River Near Jeddo	462	highest	more flashy
04159500 Black River Near Fargo	479	highest	none
04159900 Mill Creek Near Avoca	169	highest	none
04160000 Mill Creek Near Abbottsford	184	highest	N.A.*
04160050 Black River Near Port Huron	682	highest	N.A.*

* data over 25 years old

Trends

Fluctuations over time are apparent in a stream's R-B Index values. Some fluctuations in the R-B Index values are expected from year to year simply because of natural weather variations. Longer term trends result from hydrologic alterations within the watershed. Increasing flashiness stemming from higher peak flows or more frequent bankfull flows can result in changes to the channel shape: width, depth, sinuosity, and slope. These changes occur by erosion. This is especially true for stream channels that are steep and composed of noncohesive materials (Rhoads et al, 1991). Changes in stream channel shape, in turn, can have significant impacts on aquatic organism populations (Richards et al, 1997; Van Steeter et al, 1998). Because a stream can take 50 years or more to adapt to flow changes (Article 19 in Schueler, 2000), we restricted the trend analysis to gages in operation during the past 25 years. Consequently, any identified trends should be influencing the streams' morphology today.

The trends were based in part on visual examination of each gage's data, with linear regression used to objectively verify statistical significance. The linear trend lines shown in Figures 37 though 41 do not guarantee a linear relationship between flashiness and time for those streams, nor can they be used to predict future flashiness trends for those streams. The physical processes causing the changes are undoubtedly more complex. The trends identified are only intended to highlight streams experiencing flow changes that may physically alter the stream's channel morphology.

Statewide, 30 of the 210 gages in operation during the past 25 years have statistically significant decreasing trends and 41 of the gages have increasing trends, Figure 34. Many, but not all, are located near urban areas, Figure 35. This is expected because stream flow is the stream's response to many factors in a complex system – the watershed. Conversion of forest to cropland, reforestation of cropland, or a change in logging practices can have as much impact on streamflow as the transition from cropland to urban land uses. Nevertheless, urbanization, or more specifically imperviousness, has been undeniably linked with increased flashiness. When wise stormwater management is employed, adverse stream impacts can be minimized.

For the Black River watershed gages, only three of the five gages were in operation during the past 25 years. Of these three, none has a decreasing trend. One gage, 04159492, has an increasing trend, Table 12 and Figure 36. Although the14.5 square mile subbasin upstream of gage 04159492 is highlighted in Figure 36, the cause of the flashiness increase is likely not confined to that subbasin when the entire drainage area to the gage is 462 square miles. Furthermore, the next gage downstream, which does not show an increasing trend, was discontinued in 1991, but the increasing trend at 04159492 is due primarily to higher flashiness index values since 1990. It is certainly possible that if the gage were still in operation, it may also show increasing flashiness.

The R-B Index values and trends apply only to the stream in the vicinity of the gage. Conditions at other locations in the watershed may vary. For example, flashy flows in a stream above a gage may be masked by the combined flows of other streams at the gage. Similarly, streams that are increasingly flashy at one gaged location may become stable downstream due to attenuation of flashy flows by tributary flows downstream of the gage.

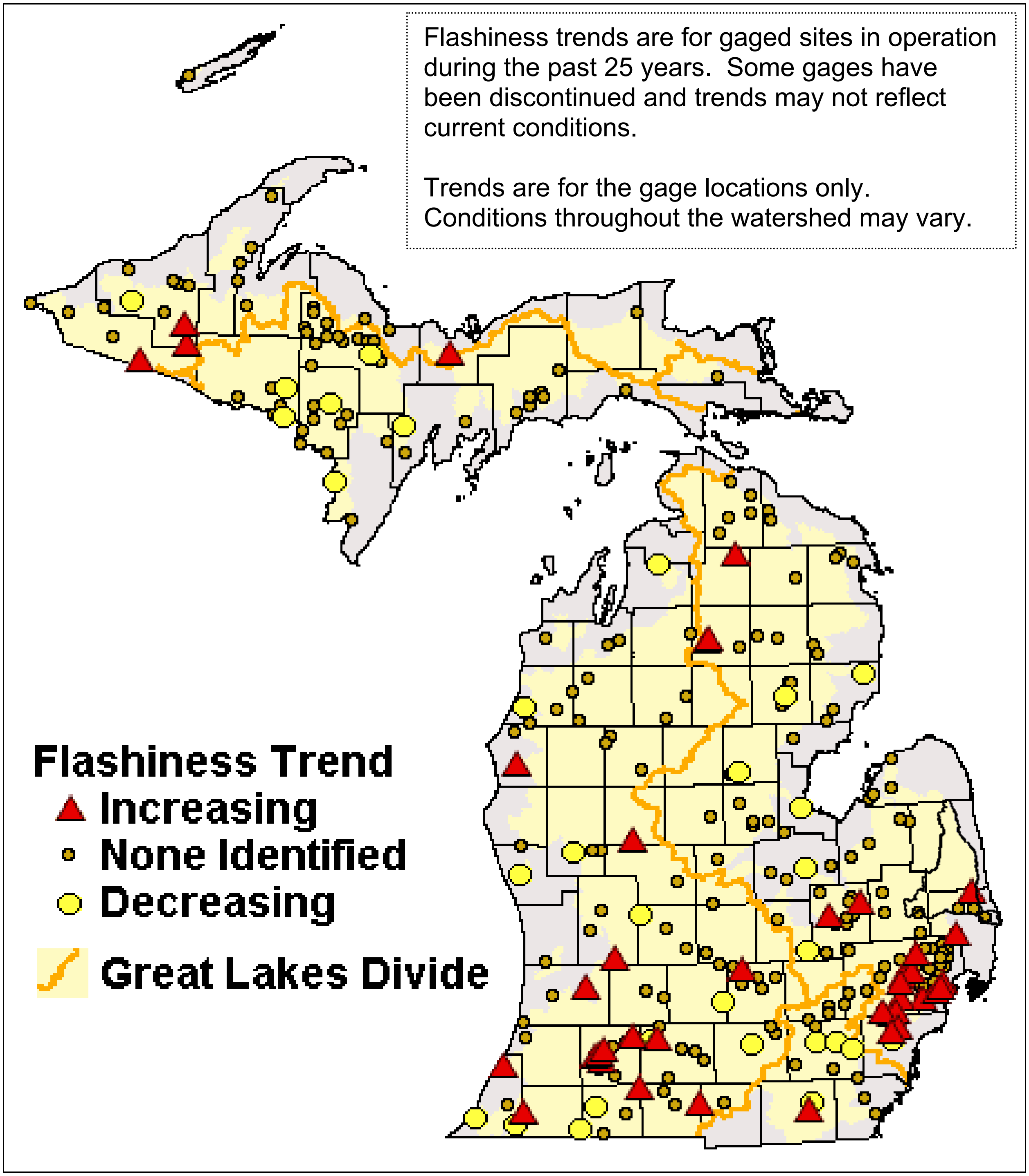


Figure 34 – Flashiness Trend by Gage, Michigan Watersheds

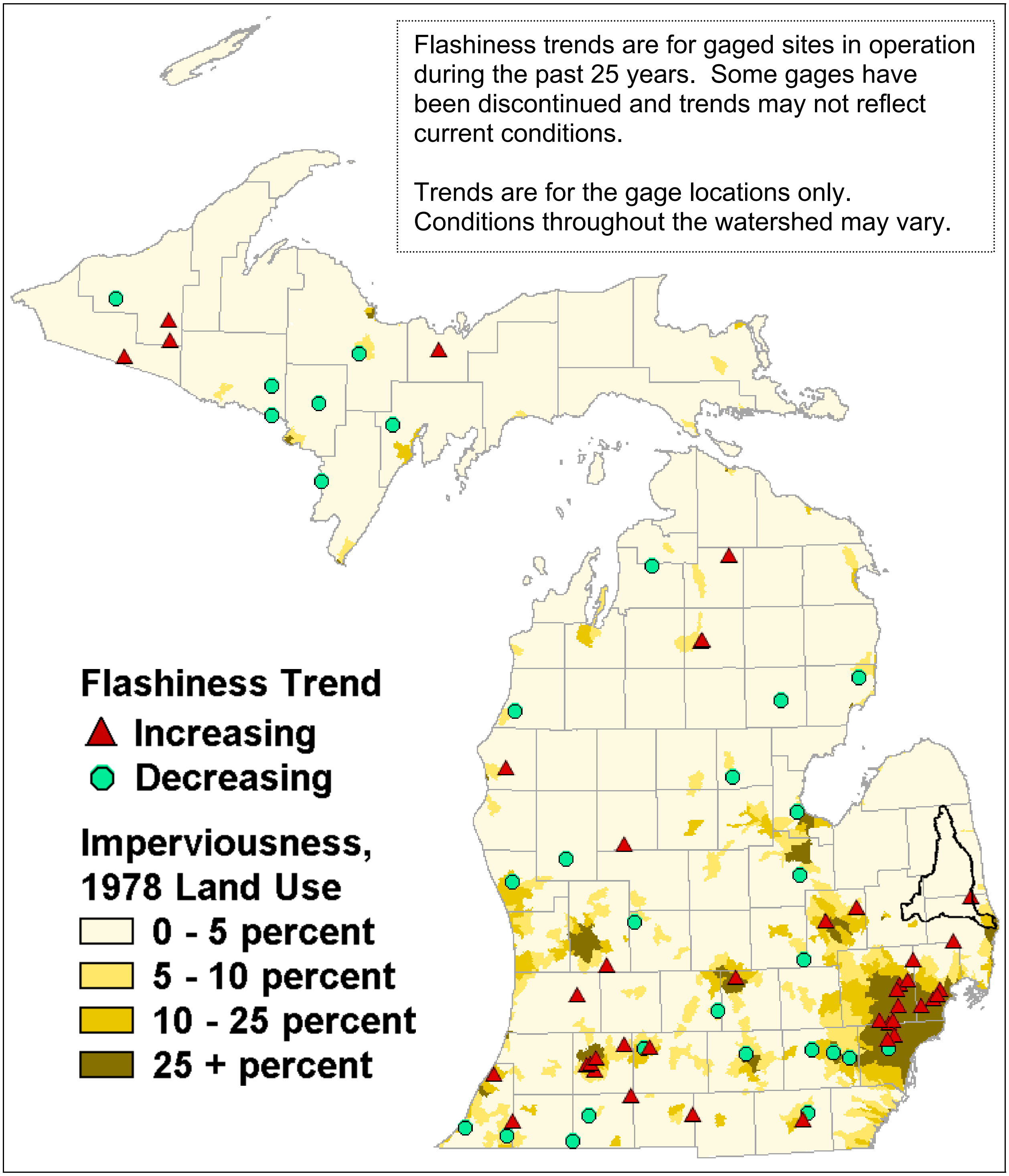


Figure 35 – Statewide Imperviousness with Flashiness Trends, 1978 Land Use

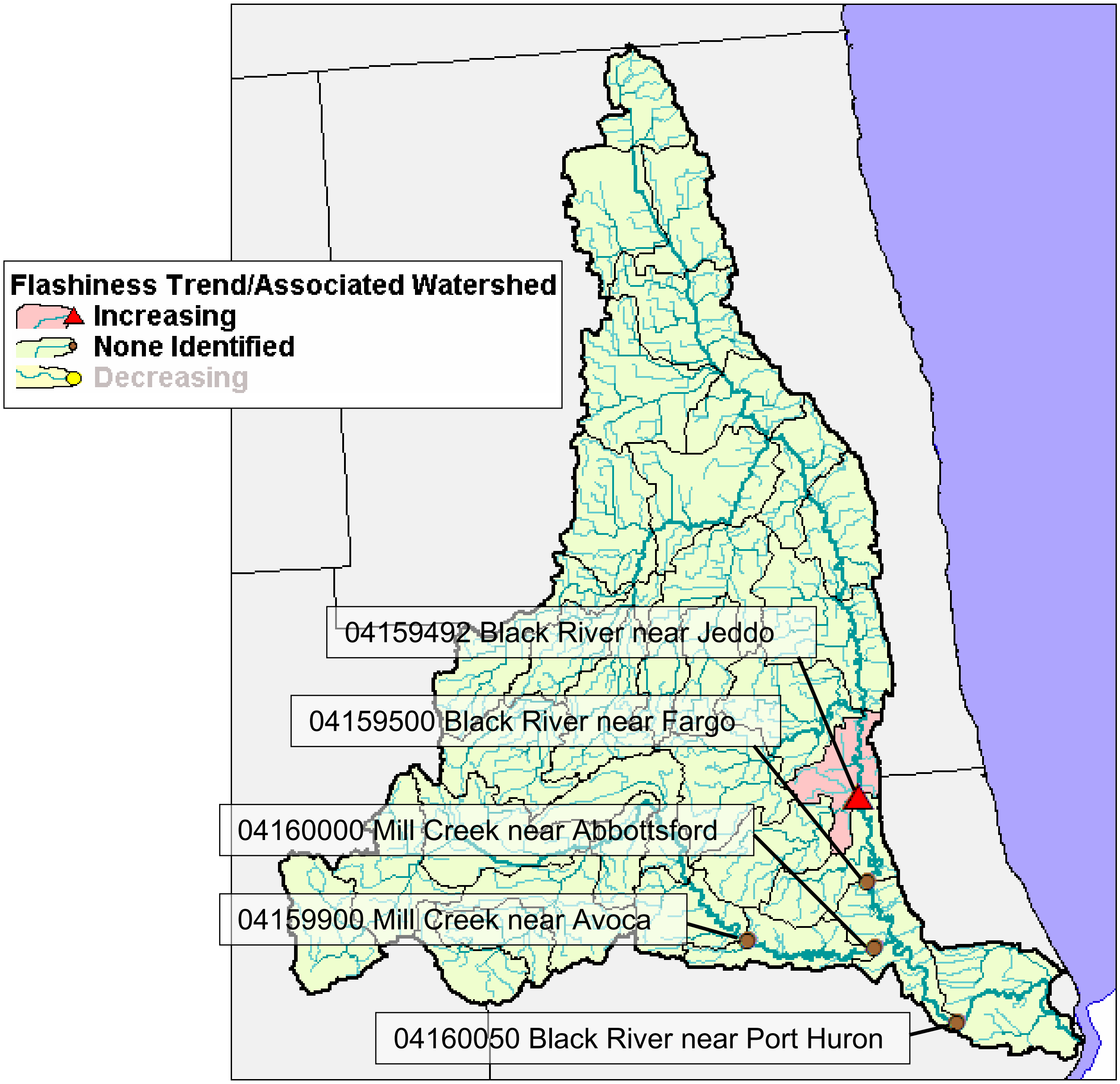


Figure 36 – Flashiness Trend by Gage, Black River Watershed

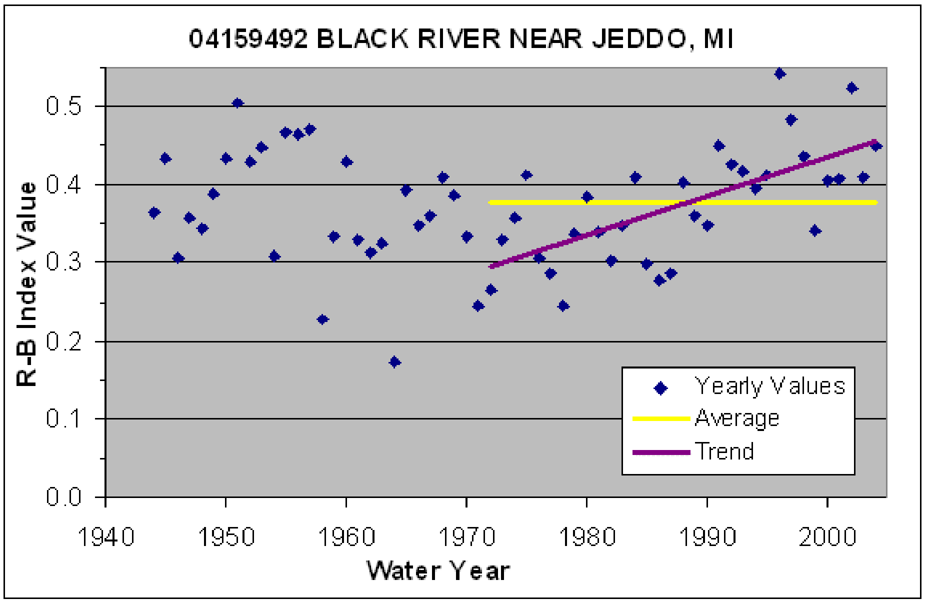
Gage Information

Graphs of the R-B Index values and trends for each gage are shown in Figures 37 through 41. The graphs are in numerical order. USGS gage stations are numbered in a downstream direction along the main stream. All stations on a tributary entering upstream from a main-stream station are listed before that station. A station on a tributary entering between two mainstream stations is listed between those stations.

The R-B Index value average is shown as a horizontal yellow line spanning the years used to calculate the average. If there is a statistically significant (i.e., $p < 0.10$) trend encompassing at least part of the past 25 years, it is represented by a sloped purple line. If a statistically significant trend change occurred, only the more recent trend is shown, and the R-B Index value average is based only on the years since that change.

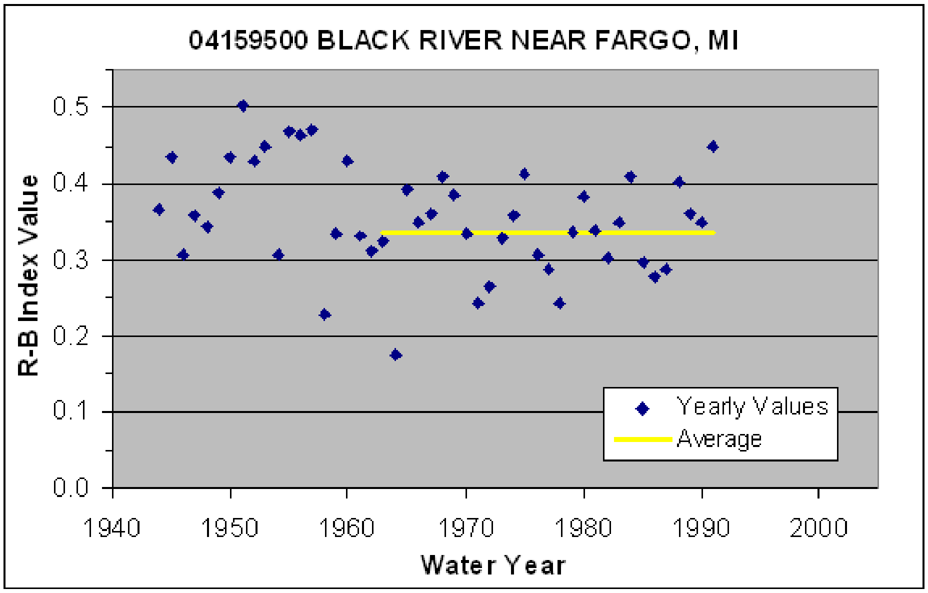
The x-axis always ends at 2005, so that the age of the data is more readily apparent. The y-axis is constrained to show gridlines every for every 0.1 increment, allowing a sense of rank relative to other gages – more gridlines equate to higher values.

R-B flashiness statistical details and gage-specific information follow each graph. Statistical significance is based on the flashiness trend regression 'p' value. A 'p' value of 0.05 or less equates to 95 percent statistical significance. A 'p' value of 0.10 or less equates to 90 percent statistical significance. Total water years may be less than the ending water year minus the starting water year because of data gaps. Some gages that may be affected by dam operations are noted, but the listing may be incomplete.



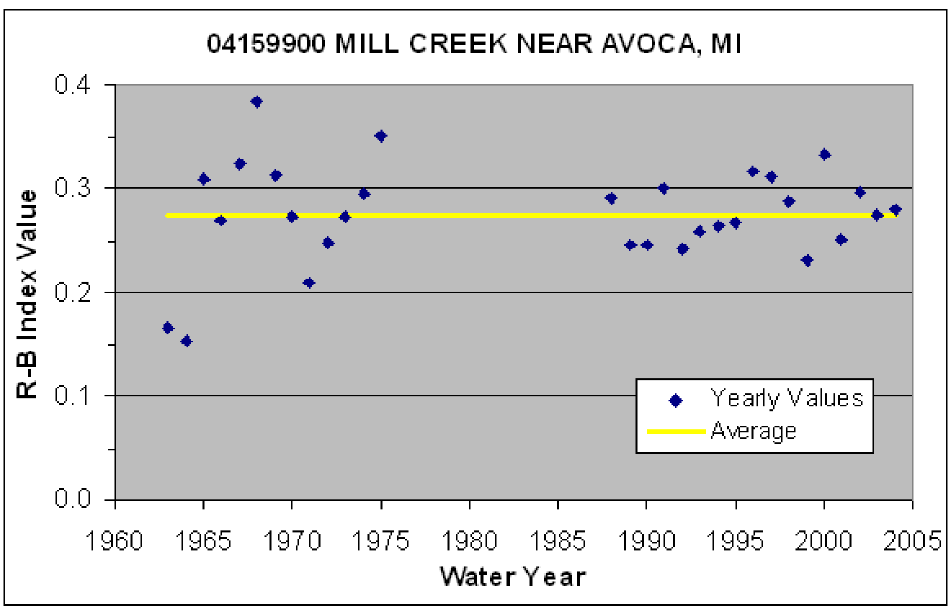
Total Drainage Area: 462 square miles Average R-B Index Value: 0.376 Rank: highest Trend: more flashy	First Water Year of Record: 1944 First Water Year of Analyzed: 1972 Last Water Year: 2004 Number of Years Analyzed: 33 p Value: <0.005
Notes: Diurnal fluctuation principally during low flow, caused by an unknown source upstream from station.	

Figure 37 – USGS Gage 04159492 Black River near Jeddo



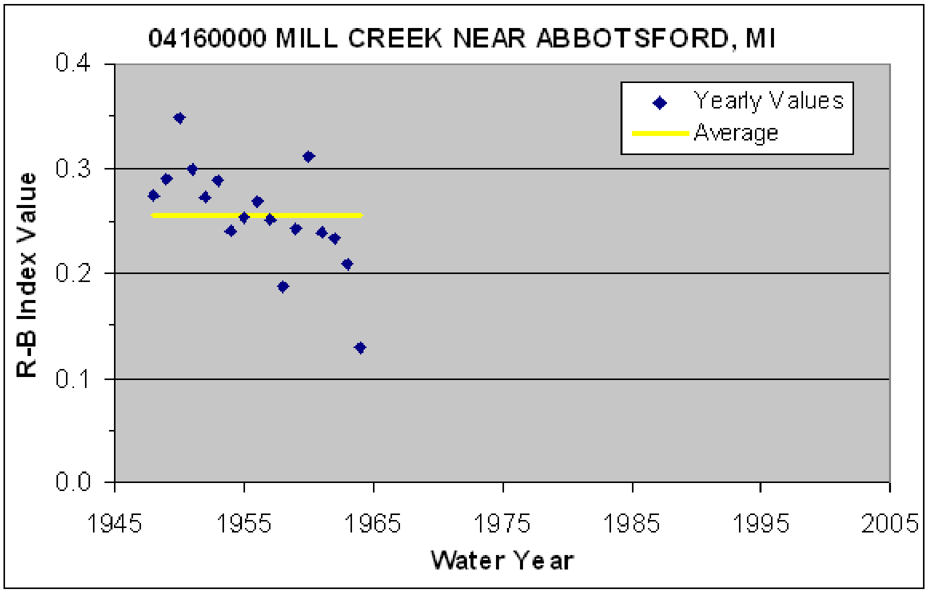
Total Drainage Area: 479 square miles Average R-B Index Value: 0.335 Rank: highest Trend: none	First Water Year of Record: 1944 First Water Year of Analyzed: 1963 Last Water Year: 1991 Number of Years Analyzed: 29
The increasing trend at 04159492 is due primarily to higher flashiness index values since 1990. This gage, 7.8 miles downstream, does not show an increasing trend, but was discontinued in 1991.	

Figure 38 – USGS Gage 04159500 Black River near Fargo



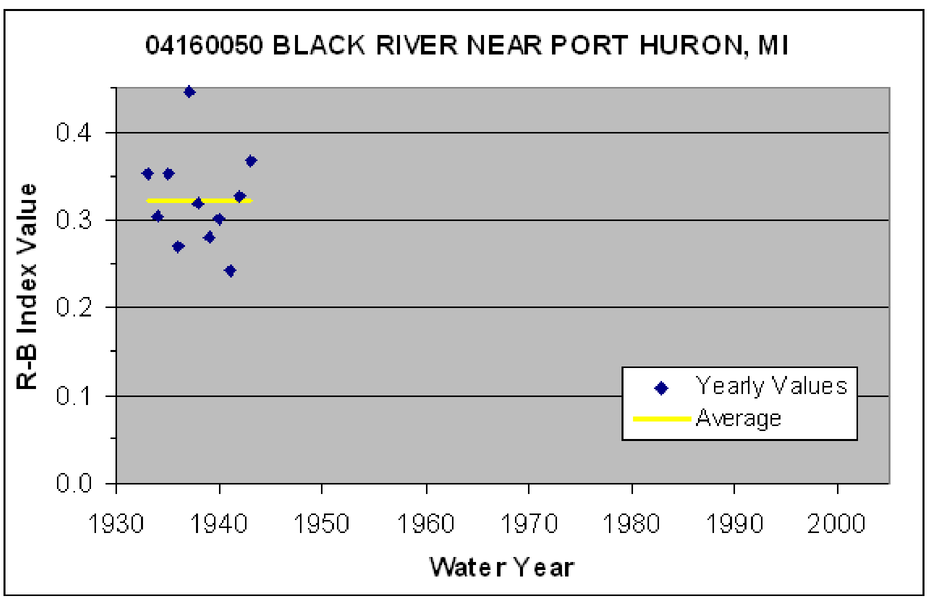
Total Drainage Area: 169 square miles Average R-B Index Value: 0.275 Rank: highest Trend: none	First Water Year of Record/Analyzed: 1963 Last Water Year: 2004 Number of Years Analyzed: 30

Figure 39 – USGS Gage 04159900 Mill Creek near Avoca



Total Drainage Area: 184 square miles Average R-B Index Value: 0.255 Rank: highest Trend: not applicable	First Water Year of Record/ Analyzed: 1948 Last Water Year: 1964 Number of Years Analyzed: 17

Figure 40 – USGS Gage 04160000 Mill Creek near Abbotsford



Total Drainage Area: 682 square miles Average R-B Index Value: 0.323 Rank: highest Trend: not applicable	First Water Year of Record/Analyzed: 1933 Last Water Year: 1943 Number of Years Analyzed: 11

Figure 41 – USGS Gage 04160050 Black River near Port Huron

Stream Morphology

Channels are shaped primarily by flows that recur fairly frequently; every one to two years in a stable stream. A stable stream is one that, over time, maintains a stable morphology: a constant pattern (sinuosity), slope, and cross-section, and neither aggrades (fills in) or degrades (erodes). A stable stream is in dynamic equilibrium, defined as “an open system in a steady state in which there is a continuous inflow and output of materials, in which the form or character of the system remains unchanged.” (Rosgen, 2006).

Stream stability is often depicted as a balance between sediment load, sediment size, stream slope, and stream discharge, Figure 42. The stream morphology will adapt so that the left side of the equation in Figure 42 balances the right side. An increase in discharge, especially channel-forming flows, increases the stream’s ability to move larger stone and soil particles, and promotes increased channel meandering and lateral bank erosion as the channel attempts to decrease its slope and enlarge its channel to restore balance.

Stream stability is not the absence of erosion; some sediment movement and streambank erosion are natural. An unstable stream is characterized by excessive, extensive erosion, with surplus sediment accumulating downstream, typically near the stream’s mouth or in a lake.

Simon (1989) defined six stages of channel evolution, Table 13. The stages describe a stream’s erosive evolution, starting with a stable channel (stage I) and ending with a refilled channel (stage VI). In between, the stream is disturbed by urbanization, forest clearing, dam construction, etc.

Table 13 – Stages of Channel Evolution

Stage	Stream Condition
I	Stream is stable.
II	Watershed’s hydrologic characteristics change – forest clearing, urbanization, dam construction, channel dredging, etc.
III	Channel instability sets in with scouring of the bed.
IV	Bank erosion and channel widening occur.
V	Banks continue to cave into the stream, widening the channel. The stream also accumulates sediment from upstream erosion.
VI	Re-equilibrium occurs and bank erosion ceases. Riparian vegetation becomes established.

The increases in stormwater runoff from 1800 to 1978 indicate that the morphology of the Black River and its tributaries have had to adapt, and may be continuing to adapt, to higher flows through channel evolution processes. It is beyond this study’s scope to identify the evolutionary stage of a specific reach of the Black River or its tributaries.

Future hydrologic changes can further impact stream morphology, as well as water quality. These changes can be moderated with effective stormwater management techniques such as treatment of the "first flush" runoff, wetland protection, retention and infiltration of excess runoff, low impact development techniques, 24-hour extended detention of 1-year flows, and properly designed detention of runoff from low probability storms. Refer to the Stormwater Management section for more detail.

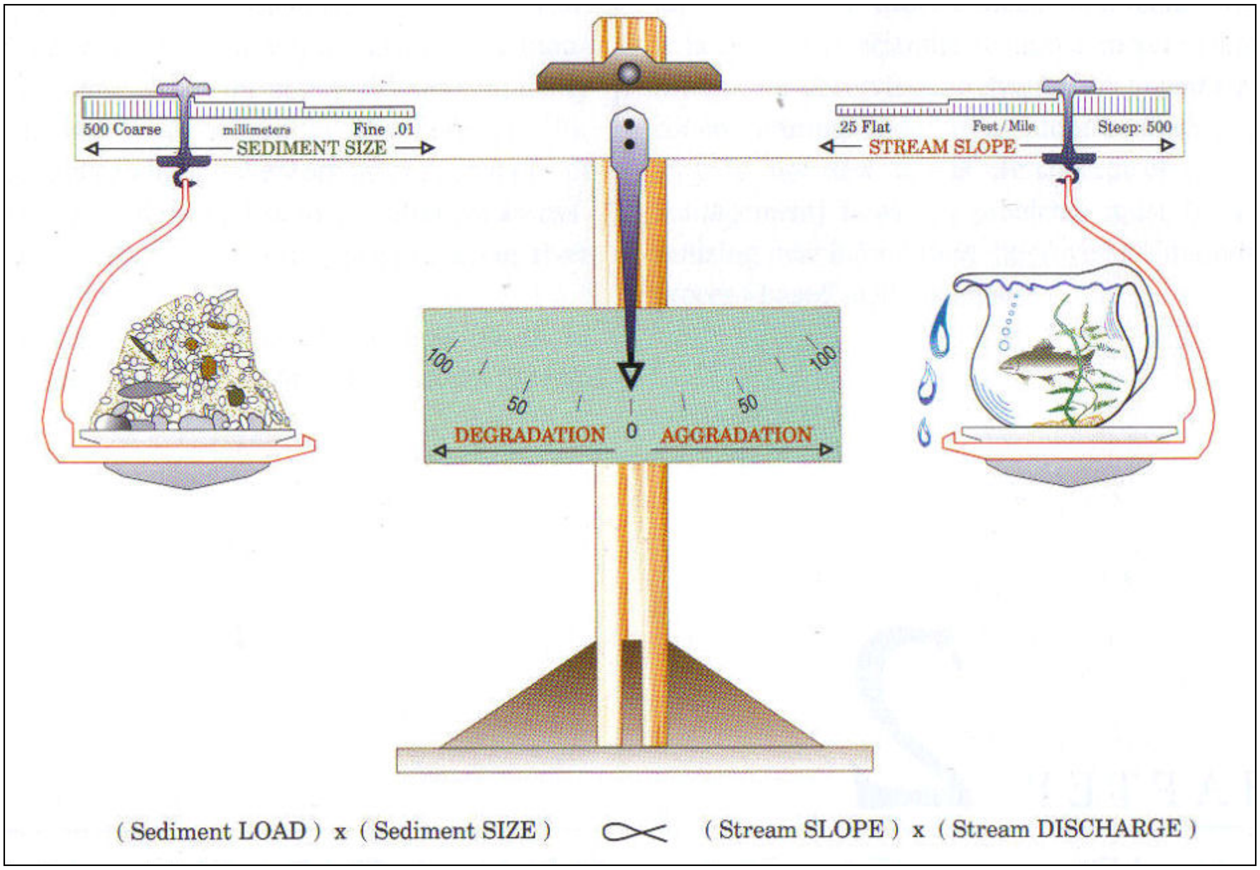


Figure 42 – Generalized Stable Channel Relationship proposed by Lane in 1955 (illustration from Rosgen 1996)

Critical Areas/Recommendations

A river or stream is affected by everything in its watershed. Watershed plans, however, identify critical areas to focus limited technical and financial resources on the parts of the watershed contributing a disproportionate share of the pollutants. For this report, critical areas are based solely on hydrologic criteria. For the watershed management plan, the Sanilac Conservation District will likely modify these selection criteria.

The selection criteria used for this report are shown in Table 14. Runoff volume per area and peak flow yield, calculated from 1978 land use, highlights those subbasins currently contributing the most runoff or are the most hydrologically responsive respectively. Changes in runoff volume per area and peak flow yield, calculated from 1800 and 1978 land use, highlights those subbasins that have experienced the most hydrologic change. Gage flashiness highlights subbasins that may be contributing to an identified increasing flashiness trend. Percent imperviousness highlights subbasins that contribute the most urban runoff. Trout streams were not used in the selection criteria because the health of a trout stream generally depends more on watershed-scale hydrologic characteristics. The results are shown in Table 15 and Figure 43.

Table 14 – Critical Area Scoring

Condition	Standard	Score
Runoff Volume per area, 1978 Land Use	0 – 0.40 inches	0
	0.41 – 0.50 inches	3
	0.51 – 0.60 inches	5
	0.61 – 0.70 inches	7
	over 0.70 inch	10
Runoff Volume Increase per area, 1800 to 1978 Land Use	decrease	0
	0.01 – 0.10 inches	3
	0.14 – 0.15 inches	5
	0.16 – 0.20 inches	7
	over 0.20 inches	10
Peak Flood Flow Yield, 1978 Land Use	0 – 0.010	0
	0.011 – 0.015	5
	0.016 – 0.020	10
Peak Flood Flow Yield Change, 1800 to 1978 Land Use	decrease	0
	0 – 50 percent	3
	51 – 100 percent	7
	101 – 150 percent	10
	Over 150 percent	20
Imperviousness	0 – 5 Percent	0
	6 – 10 Percent	5
	11 – 20 Percent	10
	21 – 25 Percent	20
	over 25 Percent	35
Gage Flashiness	No Defined Trend	0
	Upstream of Increasing Trend	10
	Adjacent to Increasing Trend	15

Table 15 – Subbasin Critical Area Scores, higher total scores highlighted with colors similar to Figure 43.

ID	Subbasin	Score						
		Runoff Volume	Runoff Volume Change	Peak Flow Yield	Peak Flow Yield Change	Imperviousness	Flashiness	Total
1	Black River below Darlington Drain	0	0	0	3	0	10	13
2	Black River above Bishop Drain	0	3	0	3	0	10	16
3	Black River below Pelton Drain	5	5	5	20	0	10	45
4	Berry Drain at Mouth	0	0	0	0	0	10	10
5	Black River below Berry Drain	3	3	5	10	0	10	31
6	Elk Creek below Lapee and Sanilac Drain	5	3	5	10	0	10	33
7	E Br Speaker and Maple Valley Drain at Mouth	5	5	0	10	0	10	30
8	Elk Creek above McDonald Drain	5	5	5	10	0	10	35
9	McDonald Drain at Mouth	3	5	0	7	0	10	25
10	Elk Creek below Beals and Frizzle Drain	5	3	5	10	0	10	33
11	Potts Drain above Spring Creek Drain	5	5	5	10	0	10	35
12	Potts Drain at Mouth	3	3	0	7	0	10	23
13	Elk Creek at Mouth	3	3	0	3	0	10	19
14	Black River below Elk Creek	0	0	0	0	0	10	10
15	Black River below Papst Drain	3	7	0	10	0	10	30
16	Black River above Arnot Drain	0	7	0	10	0	10	27
17	Black River above Black Creek	3	5	0	7	0	10	25
18	Black Creek below Jackson Creek	5	7	10	10	0	10	42
19	Black Creek at Mouth	5	5	0	3	0	10	23
20	Silver Creek at Gage #04159488	10	10	10	20	0	10	60
21	Black River at Gage #04159492	3	5	5	7	0	15	35
22	Black River at Gage #04159500	5	10	5	20	0	15	55
23	S Br Mill Creek below Weitzig Drain	10	10	10	20	0	0	50
24	S Br Mill Creek below Kolb Drain	7	5	0	7	0	0	19
25	S Br Mill Creek at Mouth	3	5	0	7	0	0	15
26	Elk Lake Creek below Brant Lake Drain	3	7	5	7	0	0	22
27	N Br Mill Creek below Madison Drain	0	3	0	7	0	0	10
28	N Br Mill Creek at Mouth	3	5	0	10	0	0	18
29	Mill Creek below Sanilac & St Clair Drain	5	7	0	10	0	0	22
30	Mill Creek above Sheehy Drain	5	7	0	10	0	0	22
31	Mill Creek at Gage #04159900	5	7	5	10	0	0	27
32	Mill Creek at Gage #04160000	5	10	0	10	0	0	25
33	Black River at Gage #04160050	0	3	0	7	0	0	10
34	Black River at Mouth	0	7	0	10	10	0	27

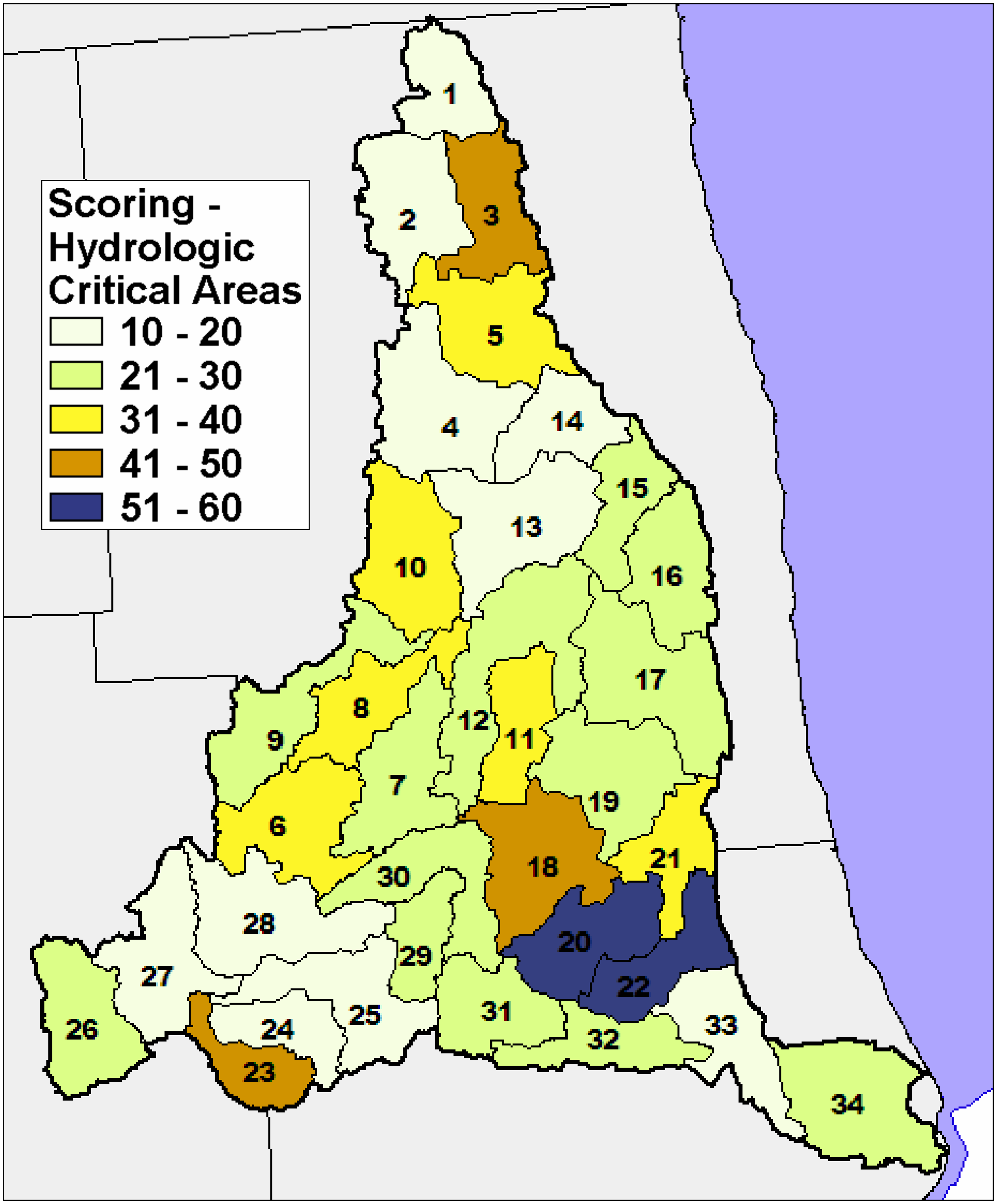


Figure 43 – Hydrologic Critical Areas

Stormwater Management

When precipitation falls, it can infiltrate into the ground, evapotranspirate back into the air, or run off the ground surface to a water body. It is helpful to consider three principal runoff effects: water quality, channel shape, and flood levels, as shown in Figure 44.

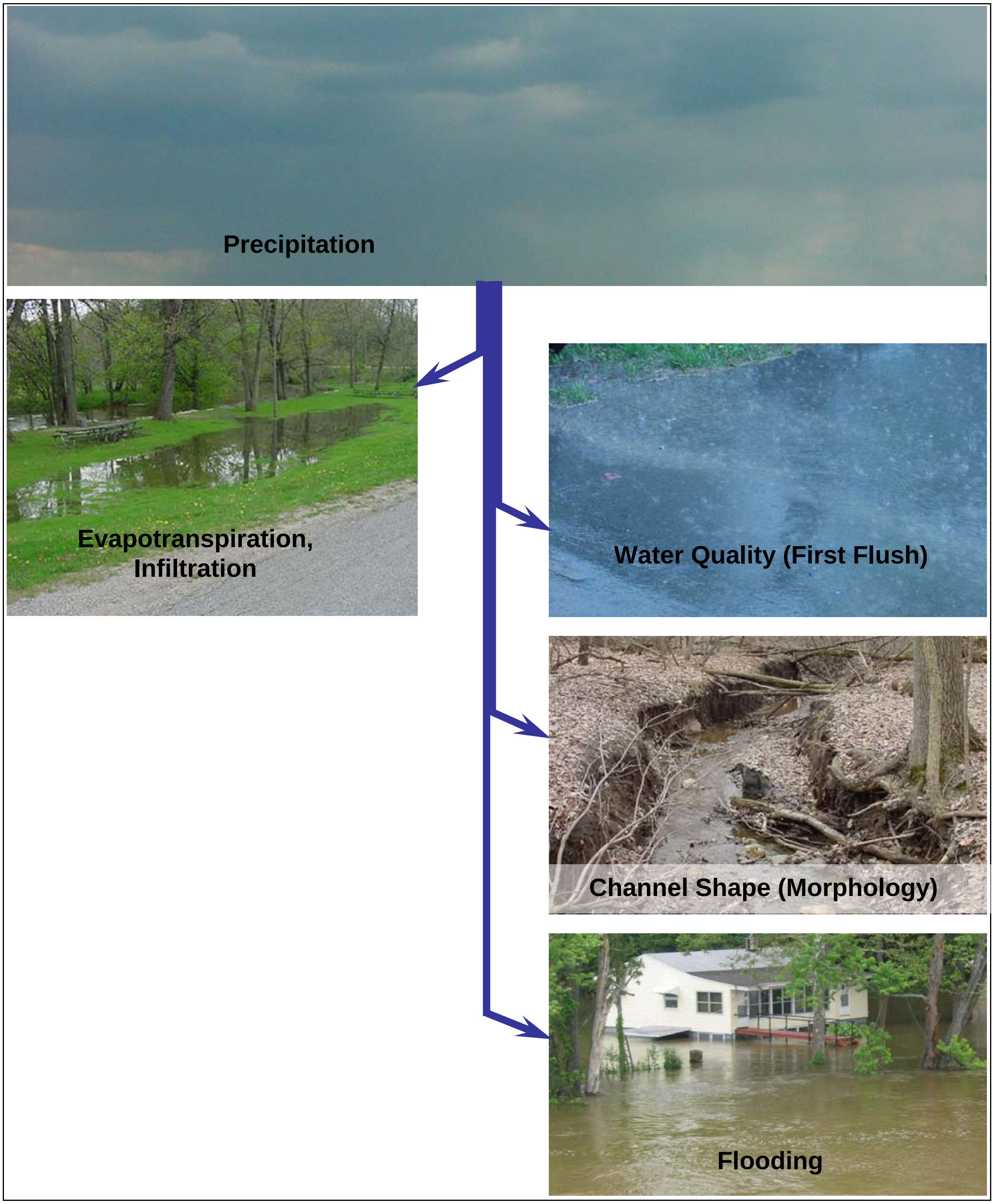


Figure 44 – Runoff Impacts

Land use changes that reduce evapotranspiration and infiltration increase runoff. One reason low impact development has become increasingly popular is that it avoids creating more runoff; intercepting and infiltrating the excess runoff instead.

Runoff from small rainfall events and the first portion of the runoff from larger events is termed the “first flush”, because it carries the majority of the pollutants. For more information, refer to the Water Quality section.

Larger, but frequent, storms or snowmelts produce the flows that shape the channel. These relatively modest storm flows, because of their higher frequency, have more effect on channel form than extreme flood flows. Hydrologic changes that increase this flow can cause the stream channel to become unstable. Stormwater management techniques used to mitigate flooding can also help mitigate projected channel-forming flow increases. However, channel-forming flow criteria should be specifically considered in the stormwater management plan so that the selected BMPs will be most effective. For example, detention ponds designed to control runoff from the 4 percent chance, 24-hour storm may do little to control the runoff from the 50 percent chance, 24-hour storm, unless the outlet is specifically designed to do so. For more information, refer to the Stream Channel Protection section.

Increases in the runoff volume and peak flow from large storms, such as the 4 percent chance (25-year), 24-hour storm, could cause or aggravate flooding problems unless mitigated using effective stormwater management techniques. For more information, refer to the Flood Protection section.

Water Quality

Small runoff events and the first portion of the runoff from larger events typically pick up and deliver the majority of the pollutants to a watercourse in an urban area (Menerey, 1999 and Schueler, 2000). As the rain continues, there are fewer pollutants available to be carried by the runoff, and thus the pollutant concentration becomes lower. Figure 45 shows a typical plot of pollutant concentration versus time. The sharp rise in the plot has been termed the "first flush." Runoff from multiple or large sites may exhibit elevated pollutant concentrations longer because the first flush runoff from some portions of the drainage area will take longer to reach the outlet. The volume of runoff recommended for treatment is calculated as follows:

- **0.5 inch of runoff** from a single impervious area. This criteria was one of the first to define the “first flush” phenomenon by studying runoff from parking lots. It has been widely used as the design water quality volume. Additional research has found that this criterion for water quality volume only applies to the runoff from a single impervious area, such as the parking lot to a single development. It is the minimum value that could be expected to capture the runoff containing the most pollutants. It is not appropriate to use for a mixture of impervious areas and pervious areas. It is also not appropriate to use for multiple impervious areas treated by a single BMP or multiple BMPs. Although it may have applications in some limited circumstances, it is not recommended that this method be used to calculate water quality volume.

- **1 inch of runoff from all impervious areas and 0.25 inches of runoff from all disturbed pervious areas.** This method provides reasonable certainty that the runoff containing the majority of pollutants from impervious areas is captured and treated by applying a simple calculation. It assumes that disturbed pervious areas contribute less runoff and therefore less pollutant to the BMPs selected. This method is recommended when the percentage of impervious area on a site is small and both pervious and impervious areas are treated by the same BMP.
- **1 inch of runoff from disturbed pervious and impervious areas.** The most conservative water quality volume calculated with a simple formula. It virtually assures that all of the first flush from any site will be captured and treated. However, when calculated this way, the water quality volume may exceed the channel protection volume. This volume determined using this method should always be compared to the channel protection volume to determine if additional water quality treatment is necessary. This method is recommended when the amount of pervious area is small or when it is desired to obtain the most conservative estimate of volume needing treatment.
- **90% of runoff producing storms.** This method determines the water quality volume by calculating the runoff generated from the 10 percent exceedance rain event for the entire site. In Michigan that event varies from 0.77 to 1.00 inches. For the Black River watershed climatic regions, the calculated value is 0.87 to 0.92 inches. This method provides a more rigorous analysis based on the site's hydrologic response. To accurately represent the pervious portion of runoff needing treatment, the runoff calculation for this method must use the small storm hydrology method described in www.michigan.gov/documents/deq/lwm-hsu-nps-ninety-percent_198401_7.pdf. The water quality volume calculated in this way produces a lower volume than using 1 inch of runoff but still assures treatment of the first flush. This method is recommended when a precise estimate of water quality volume is desired or for multiple, distributed sites treated by one BMP.

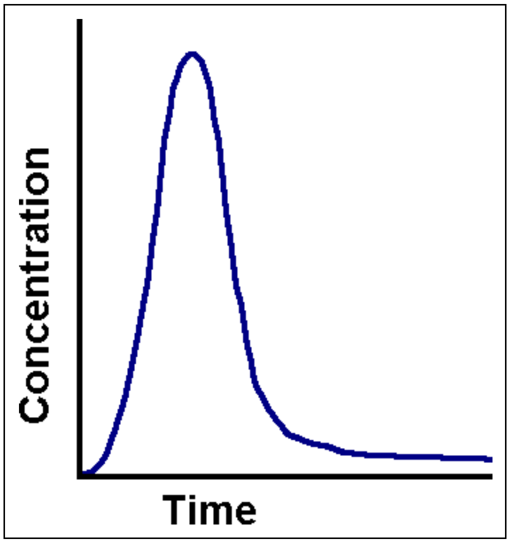


Figure 45 – Plot of Pollutant Concentration versus Time

Stream Channel Protection

A stable stream is one that, over time, maintains a stable morphology: a constant pattern (sinuosity), slope, and cross-section, and neither aggrades or degrades. Stream stability is not the absence of erosion; some sediment movement and streambank erosion are natural.

Possible causes of erosion are:

- Natural river dynamics
- Sparse vegetative cover due to too much animal or human traffic
- Concentrated runoff adjacent to the streambank, i.e. gullies, seepage
- In-stream flow obstructions, i.e. log jams, failed bridge supports
- An infrequent event, such as an ice jam or low probability flood
- Unusually large or frequent wave action
- A significant change in the hydrologic characteristics (typically land use) of the watershed
- A change in the stream form impacting adjacent portions of the stream, i.e. dredging, channelization

An assessment of the cause(s) of erosion is necessary so that proposed solutions will be permanent and do not simply move the erosion problem to another location. The first six listed causes can produce localized erosion. Either of the last two causes, however, could produce a morphologically unstable stream. Symptoms of active channel enlargement in an unstable stream include:

- Down-cutting of the channel bottom
- Extensive and excessive erosion of the stream banks
- Erosion on the inside bank of channel bends
- Evidence in the streambanks of bed erosion down through an armor layer
- Exposed sanitary or storm sewers that were initially installed under the stream bed

Erosion in a morphologically unstable stream is caused by increases in the relatively frequent channel-forming flows that, because of their higher frequency, have more effect on channel form than extreme flood flows. As shown in Figure 46, multiplying the sediment transport rate curve (a) by the storm frequency of occurrence curve (b) yields a curve (c) that, at its peak, indicates the flow that moves most of the sediment in a stream. This flow is termed the effective discharge. The effective discharge usually has a one- to two-year recurrence interval and is the dominant channel-forming flow in a stable stream.

Increases in the frequency, duration, and magnitude of these flows cause stream bank and bed erosion as the stream adapts. According to the *Stream Corridor Restoration* manual, stream channels can often enlarge their cross-sectional area by a factor of 2 to 5 (FISRWG, 10/1998). In *Dynamics of Urban Stream Channel Enlargement, The Practice of Watershed Protection*, ultimate channel enlargement ratios of up to approximately 10 are reported, as shown in Figure 47 (Schueler and Holland, 2000). To prevent or minimize this erosion, watershed stakeholders should specifically consider stormwater management to protect channel morphology. Low impact development and infiltration BMPs can be incorporated to offset flow increases. Stormwater management ordinances can specifically address channel protection. However, where ordinances have included channel protection criteria, it has typically been focused on controlling peak flows from the 2-year storm.

The nationally recognized Center for Watershed Protection asserts that 24-hour extended detention for runoff from 1-year storms better protects channel morphology than 2-year peak discharge control because it does not reduce the frequency of erosive bankfull and sub-bankfull flows that often increase as development occurs within the watershed. Indeed, it may actually increase the duration of these erosive, channel-forming flows. The intent of 24-hour extended detention for runoff from 1-year storms is to limit detention pond outflows from these storms to non-erosive velocities, as shown in Figure 48. A few watershed plans funded through the MDEQ Nonpoint Source Program have recommended requirements based on this criterion. One such example is from the Anchor Bay Technical Report shown in Figure 49. This analysis, which is for climatic region 10, is for 2.06 inches of rainfall. The Black River watershed spans climatic regions 7 and 10, which have 50 percent chance (2-year) 24-hour storm design rainfall values of 2.14 and 2.20 inches respectively, as tabulated in *Rainfall Frequency Atlas of the Midwest*, Bulletin 71, Midwestern Climate Center, 1992, pp. 126-129. The MDEQ Nonpoint Source Program is funding this analysis for western Michigan through the Lower Grand Initiatives grant, 2007-0137, to the Grand Valley Metropolitan Council.

Detention designed to control channel-forming flows and prevent streambank erosion may not be needed for runoff routed from a city through storm sewers to a large river, such as the Black River at Port Huron, simply because the runoff routed through the storm sewers enters the river well ahead of the peak flow in the river. In this case, the management plan for stormwater routed through storm sewers should focus on treating the runoff to maintain water quality and providing sufficient drainage capacity to minimize flooding. Detention/retention might also be encouraged or required for other reasons, such as water quality improvement, groundwater replenishment, or if watershed planning indicates continued regional development would alter the river's flow regime or increase flood levels.

Hydrologic and hydraulic modeling may be justified to determine if runoff from a drainage area should be limited, either by detention or infiltration, to prevent flow or flood level increases or to verify that flood peaks are not increased due to the timing of the peak flows from detention ponds and in the stream. Black River watershed stakeholders may elect to recommend some conditions when detention or retention for channel protection is not necessary. For example, the watershed stakeholders may adopt a watershed plan that calls for channel protection measures, unless runoff discharges from a storm drain directly to a specific order or higher stream, as shown in Figure 6.

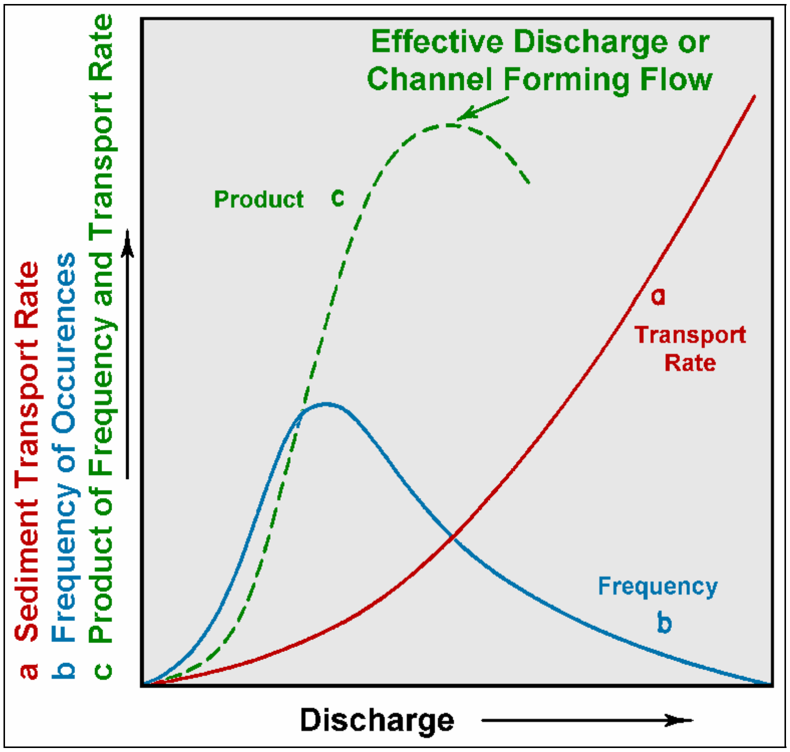


Figure 46 – Effective Discharge (from *Applied River Morphology*. 1996. Dave Rosgen)

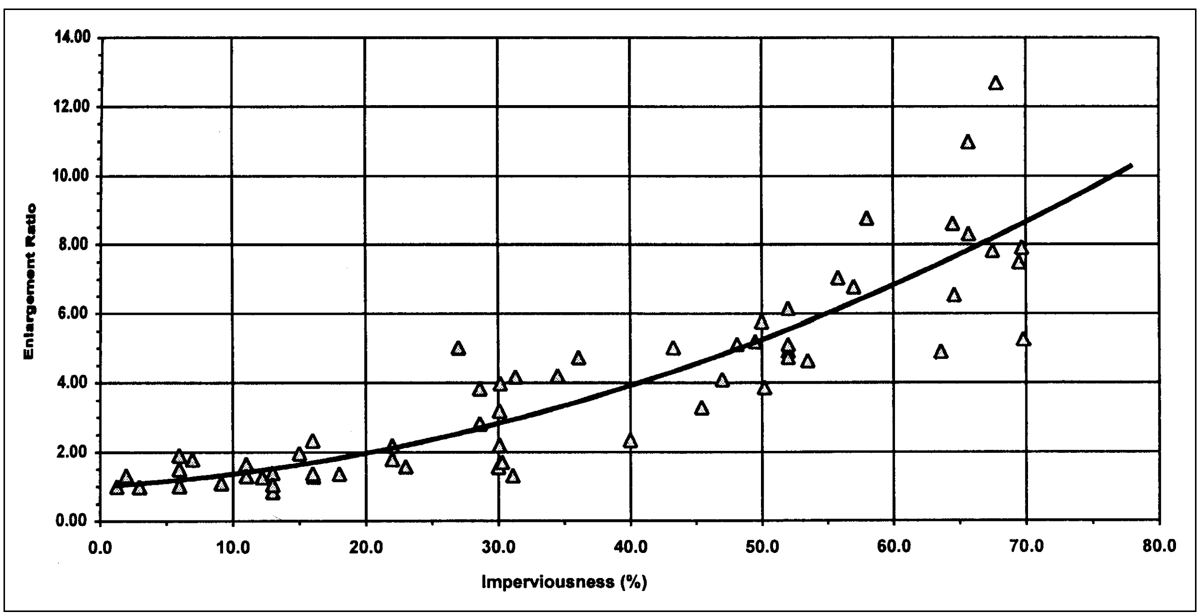


Figure 47 – "Ultimate" Channel Enlargement as a Function of Impervious Cover in Alluvial Streams in Maryland, Vermont, and Texas (MacRae and DeAndrea, 1999; and Brown and Claytor, 2000) (From *The Practice of Watershed Protection*, Thomas R. Schueler and Heather K. Holland, 2000)

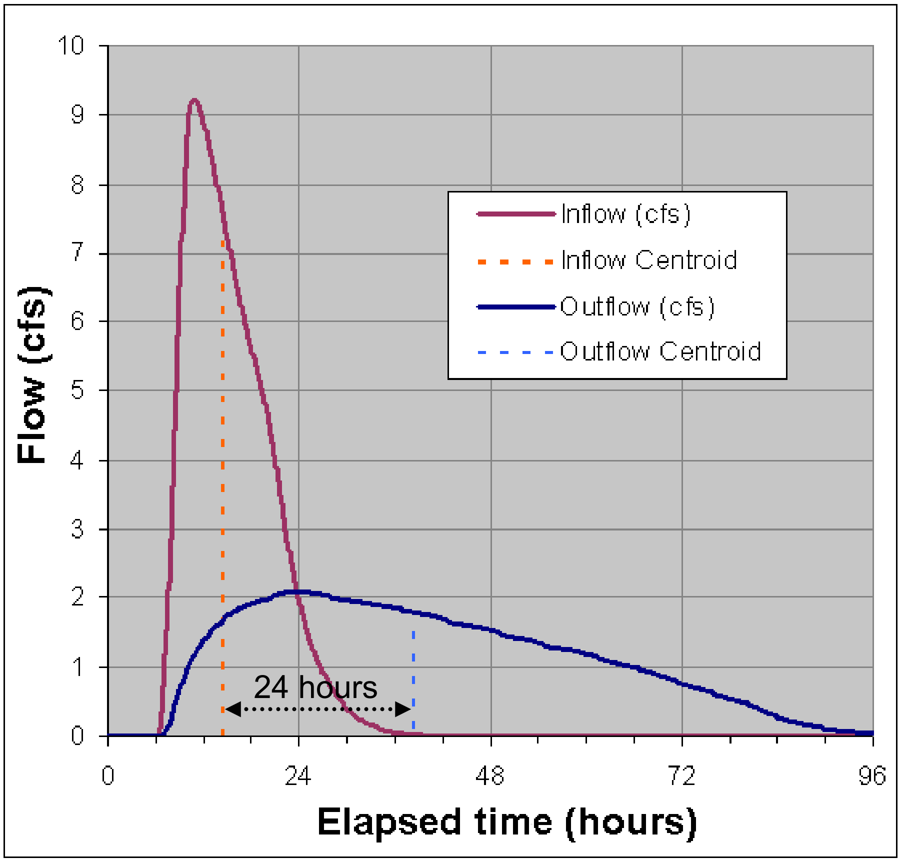


Figure 48 – Example of 24-hour extended detention criterion applied to detention pond design

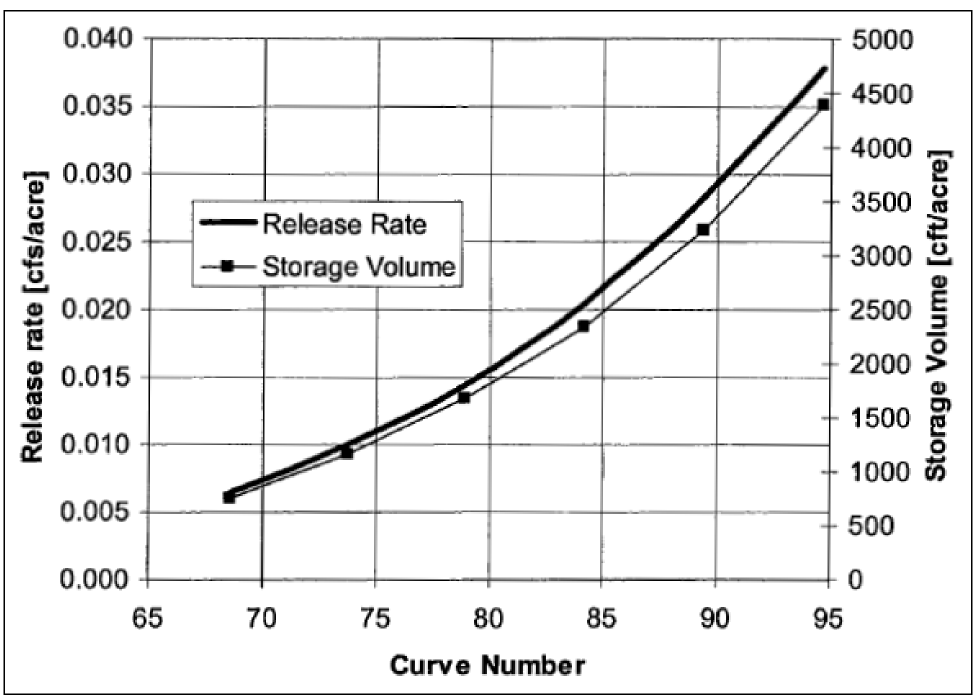


Figure 49 – Example of detention pond requirements derived from the 24-hour extended detention criterion

Flood Protection

A river, stream, lake, or drain may occasionally overflow its banks and inundate adjacent land. This land is the floodplain. The floodplain refers to the land inundated by the 1 percent chance flood, commonly called the 100-year flood. Typically, a stable stream will recover naturally from these infrequent events. Developments should always include stormwater controls that prevent flood flows from exceeding pre-development conditions and putting people, homes, and other structures at risk. Many localities require new development to control the 4 percent chance flood, commonly called the 25-year flood, with some adding requirements to control the 1 percent chance flood.

References

Anchor Bay Watershed Transition/Implementation Project, Technical Report for Watershed Management Plan, Fishbeck, Thompson, Carr and Huber, April 2006. www.michigan.gov/deq/0,1607,7-135-3313_3682_3714_31581-104205--,00.html

Baker, D.B., P. Richards, T.L. Loftus, and J.W. Kramer. 2004. A New Flashiness Index: Characteristics and Applications to Midwestern Rivers and Streams. *Journal of the American Water Resources Association* 40(2):503 – 522, www.awra.org/jawra/papers/J03095.html

FISRWG (10/1998). Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (15 Federal agencies of the US government). GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3. www.nrcs.usda.gov/technical/stream_restoration/

Fongers, D. and J. Henderson. *Peak Flow Analysis of Michigan USGS Gages*. Michigan Department of Environmental Quality, Land and Water Management Division, March 2006, www.michigan.gov/documents/deq/lwm-hsu-nps-qpeak_201711_7.pdf

Fongers, D., J. Rathbun, and K. Manning. *Application of the Richards-Baker Flashiness Index to Gaged Michigan Rivers and Streams*. Michigan Department of Environmental Quality, Land and Water Management Division, August 2007, www.michigan.gov/documents/deq/lwm-hsu-rb-flashiness_204776_7.pdf

Fraley-McNeal, L. personal communication. 9/10/2008

Guidebook of Best Management Practices for Michigan Watersheds. Michigan Department of Environmental Quality, Surface Water Quality Division, 1993 (Reprinted October 1998). www.deq.state.mi.us/documents/deq-swq-nps-WholeGuidebook.pdf

Hawkins, R.H., A.T. Hjelmfelt, and A.W. Zevenbergen. 1985. Runoff Probability, Storm Depth, and Curve Numbers. J. Irr. and Drain. ASCE, Vol. 111, No. 4, pp. 330-340. www.pubs.asce.org/WWWdisplay.cgi?8503450

Menerey, Bruce, *Stormwater Management Guidebook.* Michigan Department of Natural Resources, Land and Water Management Division, March 1992 (Revised August 1999 and distributed by Michigan Department of Environmental Quality, Land and Water Management Division). www.michigan.gov/documents/deq/lwm-smg-all_202833_7.pdf

Rhoads, B. and M. Miller. 1991. Impact of Flow Variability on the Morphology of a Low-Energy Meandering River. *Earth Surface Processes and Landforms* 16:357-367.

Richards, C., R. Haro, L. Johnson, and G. Host. 1997. Catchment and Reach-Scale Properties as Indicators of Macroinvertebrate Species Traits. *Freshwater Biology* 37:219-230.

Rosgen, Dave, Applied River Morphology. Printed Media Companies, Minneapolis, Minnesota, 1996.

Rosgen, Dave, Watershed Assessment of River Stability and Sediment Supply (WARSSS). Friesens, Altona, Manitoba, Canada, 2006.

Schueler, T.R. and H.K. Holland, editors. The Importance of Imperviousness, Article 1 (p. 7 - 18) in The Practice of Watershed Protection, Center for Watershed Protection. Elliot City, Maryland, 2000.

Schueler, T.R. and H.K. Holland, editors. Dynamics of Urban Stream Channel Enlargement, Article 19 (p. 99 - 104) in The Practice of Watershed Protection, Center for Watershed Protection. Elliot City, Maryland, 2000.

Simon, Andrew, The Discharge Of Sediment In Channelized Alluvial Streams, Journal of the American Water Resources Association 25 (6), 1177–1188. 1989

Sorrell, Richard C., Computing Flood Discharges for Small Ungaged Watersheds, Michigan DEQ, revised July 2008. www.michigan.gov/documents/deq/lwm-scs_198408_7.pdf

United States Department of Agriculture, Natural Resources Conservation Service. *Urban Hydrology for Small Watersheds TR-55*, June 1986

Van Steeter, M. and J. Pitlick. 1998. Geomorphology and Endangered Fish Habitats of the Upper Colorado River: 1. Historic Changes in Streamflow, Sediment Load, and Channel Morphology. *Water Resources Research* 34:287-302.

Appendix A: Black River Hydrologic Parameters

Table A1 provides the hydrologic parameters specified for each of the subbasin elements in the hydrologic analysis.

Table A1 – Subbasin Parameters

ID	Subbasin	Drainage Area (sq. mi.)	CN 1800	CN 1978	Tc (hours)	SC
1	Black River below Darlington Drain	14.9	70.9	68.6	16.75	32.79
2	Black River above Bishop Drain	22.2	74.3	73.9	34.59	87.14
3	Black River below Pelton Drain	19.0	73.1	75.9	18.37	21.60
4	Berry Drain at Mouth	29.0	77.4	64.3	28.30	36.18
5	Black River below Berry Drain	24.2	73.8	75.4	23.69	29.30
6	Elk Creek below Lapee and Sanilac Drain	23.8	76.0	77.5	20.11	25.73
7	East Branch Speaker and Maple Valley Drain at Mouth	22.5	74.4	77.3	28.21	39.01
8	Elk Creek above McDonald Drain	18.2	73.8	76.6	27.77	34.36
9	McDonald Drain at Mouth	23.6	75.0	76.1	42.88	56.86
10	Elk Creek below Beals and Frizzle Drain	24.1	75.1	77.1	25.66	25.66
11	Potts Drain above Spring Creek Drain	15.1	74.6	77.0	21.32	30.54
12	Potts Drain at Mouth	31.2	73.1	74.1	37.89	62.31
13	Elk Creek at Mouth	28.5	74.7	75.2	48.97	96.30
14	Black River below Elk Creek	15.9	72.7	68.5	27.59	55.79
15	Black River below Papst Drain	14.6	66.5	72.9	15.13	31.86
16	Black River above Arnot Drain	19.4	66.9	74.4	43.94	90.12
17	Black River above Black Creek	31.1	71.1	75.4	46.75	96.94
18	Black Creek below Jackson Creek	25.6	72.9	77.6	15.83	22.55
19	Black Creek at Mouth	24.9	73.9	77.8	24.84	51.58
20	Silver Creek at Gage #04159488	20.3	74.5	80.6	23.25	25.62
21	Black River at Gage #04159492	14.5	69.5	73.1	13.36	23.83
22	Black River at Gage #04159500	16.9	70.3	76.3	26.11	30.71
23	South Branch Mill Creek below Weitzig Drain	11.9	74.7	80.9	17.85	23.64
24	South Branch Mill Creek below Kolb Drain	12.8	76.5	78.6	27.79	49.45
25	South Branch Mill Creek at Mouth	23.2	75.5	77.0	56.65	102.47
26	Elk Lake Creek below Brant Lake Drain	20.6	67.3	73.5	13.30	27.78
27	North Branch Mill Creek below Madison Drain	23.2	67.0	69.1	19.74	33.37
28	North Branch Mill Creek at Mouth	27.6	73.8	75.9	38.77	54.11
29	Mill Creek below Sanilac & St Clair Drain	11.3	72.2	76.7	35.18	44.27
30	Mill Creek above Sheehy Drain	20.3	72.0	76.4	39.71	55.97
31	Mill Creek at Gage #04159900	17.3	73.2	77.5	27.06	34.06
32	Mill Creek at Gage #04160000	15.3	69.7	76.2	29.30	33.34
33	Black River at Gage #04160050	19.2	63.4	66.7	66.43	90.59
34	Black River at Mouth	27.8	69.5	73.7	45.92	72.77

Appendix B: Glossary

Aggrade - to fill and raise the level of a stream bed by deposition of sediment.

Alluvium - sediment deposited by flowing rivers and consisting of sands and gravels.

Bankfull discharge - that discharge of stream water that just begins to overflow in the active floodplain. The active floodplain is defined as a flat area adjacent to the channel constructed by the river and overflowed by the river at recurrence interval of about 2 years or less. Erosion, sediment transport, and bar building by deposition are most active at discharges near bankfull. The effectiveness of higher flows, called over bank or flood flows, does not increase proportionally to their volume above bankfull in a stable stream, because overflow into the floodplain distributes the energy of the stream over a greater area. See also channel-forming and effective discharge.

Base Flow - the part of stream flow that is attributable to long-term discharge of groundwater to the stream. This part of stream flow is not attributable to short-term surface runoff, precipitation, or snow melt events.

Best Management Practice (BMP) - structural, vegetative, or managerial practices used to protect and improve our surface waters and groundwaters.

Channel-forming Discharge - a theoretical discharge which would result in a channel morphology close to the existing channel. See also effective and bankfull discharge.

Critical Areas - the geographic portions of the watershed contributing the majority of the pollutants and having significant impacts on the waterbody.

Critical Depth - depth of water for which specific energy is a minimum.

Curve Number - see Runoff Curve Number.

Design Flow - projected flow through a watercourse which will recur with a stated frequency. The projected flow for a given frequency is calculated using statistical analysis of peak flow data or using hydrologic analysis techniques.

Detention - practices which store stormwater for some period of time before releasing it to a surface waterbody. See also retention.

Dimensionless Hydrograph - a general hydrograph developed from many unit hydrographs, used in the Soil Conservation Service method.

Direct Runoff Hydrograph - graph of direct runoff (rainfall minus losses) versus time.

Discharge - volume of water moving down a channel per unit time. See also channel-forming, effective, and bankfull discharge.

Drainage Divide - boundary that separates subbasin areas according to direction of runoff.

Effective Discharge - the calculated measure of channel forming discharge. This calculation requires long-term water and sediment measurements, although modeling results are sometimes substituted. See also channel-forming and bankfull discharge.

Ephemeral Stream - a stream that flows only during or immediately after periods of precipitation. See also intermittent and perennial streams.

Evapotranspiration - the combined process of evaporation and transpiration.

First Flush - the first part of a rainstorm that washes off the majority of pollutants from a site. The concept of first flush treatment applies only to a single site, even if just a few acres, because of timing of the runoff. Runoff from multiple or large sites may exhibit elevated pollutant concentrations longer because the first flush runoff from some portions of the drainage area will take longer to reach the outlet.

Flashiness - has no set definition but is associated with the rate of change of flow. Flashy streams have more rapid flow changes.

Flood Hazard Zone - area that will flood with a given probability.

Groundwater - that part of the subsurface water that is in the saturated zone.

Headwater Stream - the system of wetlands, swales, and small channels that mark the beginnings of most watersheds.

Hydraulic Analysis - an evaluation of water elevation for a given flow based on channel attributes such as slope, cross-section, and vegetation.

Hydrograph - graph of discharge versus time.

Hydrogroups - Soil groups used to estimate runoff from precipitation according to the infiltration of water when the soils receive precipitation from long-duration storms.

Hydrologic Analysis - an evaluation of the relationship between stream flow and the various components of the hydrologic cycle. The study can be as simple as determining the watershed size and average stream flow, or as complicated as developing a computer model to determine the relationship between peak flows and watershed characteristics, such as land use, soil type, slope, rainfall amounts, detention areas, and watershed size.

Hydrologic Cycle - When precipitation falls to the earth, it may:

- be intercepted by vegetation, never reaching the ground.
- infiltrate into the ground, be taken up by vegetation, and evapotranspirated back to the atmosphere.
- enter the groundwater system and eventually flow back to a surface water body.
- runoff over the ground surface, filling in depressions.
- enter directly into a surface waterbody, such as a lake, stream, or ocean.

When water evaporates from lakes, streams, and oceans and is re-introduced to the atmosphere, the hydrologic cycle starts over again.

Hydrology - the occurrence, distribution, and movement of water both on and under the earth's surface. It can be described as the study of the hydrologic cycle.

Hyetograph - graph of rainfall intensity versus time.

Impervious - a surface through which little or no water will move. Impervious areas include paved parking lots and roof tops.

Infiltration Capacity - rate at which water can enter soil with excess water on the surface.

Interflow - flow of water through the upper soil layers to a ditch, stream, etc.

Intermittent Stream - a stream that flows only during certain times of the year. Seasonal flow in an intermittent stream usually lasts longer than 30 days per year. See also ephemeral and perennial streams.

Invert - bottom of a channel or pipe.

Knickpoint - a point of abrupt change in bed slope. If the streambed is made of erodible material, the knickpoint, or downcut, may migrate upstream along the channel and have undesirable effects, such as undermining bridge piers and other manmade structures.

Lag Time - time from the center of mass of the rainfall to the peak of the hydrograph.

Low Impact Development (LID) - a comprehensive design and development technique that strives to mimic pre-development hydrologic characteristics and water quality with a series of small-scale distributed structural and non-structural controls.

Losses - rainfall that does not runoff, i.e. rainfall that infiltrates into the ground or is held in ponds or on leaves, etc.

Low Flow - minimum flow through a watercourse which will recur with a stated frequency. The minimum flow for a given frequency may be based on measured data, calculated using statistical analysis of low flow data, or calculated using hydrologic analysis techniques. Projected low flows are used to evaluate the impact of discharges on water quality. They are, for example, used in the calculation of industrial discharge permit requirements.

Morphology, Fluvial - the study of the form and structure of a river, stream, or drain.

Nonpoint Source Pollution - pollutants carried in runoff characterized by multiple discharge points. Point sources emanate from a single point, generally a pipe.

Overland Flow - see Runoff.

Peak Flow - maximum flow through a watercourse which will recur with a stated frequency. The maximum flow for a given frequency may be based on measured data, calculated using statistical analysis of peak flow data, or calculated using hydrologic analysis techniques. Projected peak flows are used in the design of culverts, bridges, and dam spillways.

Perched Ground Water - unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone.

Perennial Stream - a stream that flows continuously during both wet and dry times. See also ephemeral and intermittent streams.

Precipitation - water that falls to earth in the form of rain, snow, hail, or sleet.

Rating Curve - relationship between depth and amount of flow in a channel.

Recession Curve - portion of the hydrograph where runoff is from base flow.

Retention - practices which capture stormwater and release it slowly though infiltration into the ground. See also detention.

Riparian - pertaining to the bank of a river, pond, or small lake.

Runoff - flow of water across the land surface as surface runoff or interflow. The volume is equal to the total rainfall minus losses.

Runoff Coefficient - ratio of runoff to precipitation.

Runoff Curve Number - parameter developed by the Natural Resources Conservation Service (NRCS) that accounts for soil type and land use.

Saturated Zone - (1) those parts of the earth's crust in which all voids are filled with water under pressure greater than atmospheric; (2) that part of the earth's crust beneath the regional water table in which all voids, large and small, are filled with water under pressure greater than atmospheric; (3) that part of the earth's crust beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

Scarp - the sloped bank of a stream channel.

Sediment - soil fragmental material that originates from weathering of rocks and is transported or deposited by air, water, or ice.

Sinuosity - the ratio of stream length between two points divided by the valley length between the same two points.

Simulation Model - model describing the reaction of a watershed to a storm using numerous equations.

Soil - unconsolidated earthy materials which are capable of supporting plants. The lower limit is normally the lower limit of biological activity, which generally coincides with the common rooting of native perennial plants.

Soil Moisture Storage - volume of water held in the soil.

Storage Delay Constant - parameter that accounts for lagging of the peak flow through a channel segment.

Storage-Discharge Relation - values that relate storage in the system to outflow from the system.

Stream Corridor - generally consists of the stream channel, floodplain, and transitional upland fringe.

Subbasins - hydrologic divisions of a watershed that are relatively homogenous.

Synthetic Design Storm - rainfall hyetograph obtained through statistical means.

Synthetic Unit Hydrograph - unit hydrograph for ungaged basins based on theoretical or empirical methods

Thalweg - the "channel within the channel" that carries water during low-flow conditions.

Time of Concentration - time at which outflow from a basin is equal to inflow or time of equilibrium.

Transpiration - conversion of liquid water to water vapor through plant tissue.

Tributary - a river or stream that flows into a larger river or stream.

Unit Hydrograph - graph of runoff versus time produced by a unit rainfall over a given duration.

Unsaturated Zone - the zone between the land surface and the water table which may include the capillary fringe. Water in this zone is generally under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric.

Vadose Zone - see Unsaturated Zone.

Watershed - area of land that drains to a single outlet and is separated from other watersheds by a divide.

Watershed Delineation - determination of watershed boundaries. These boundaries are determined by reviewing USGS quadrangle maps. Surface runoff from precipitation falling anywhere within these boundaries will flow to the waterbody.

Water Surface Profile - plot of the depth of water in a channel along the length of the channel.

Water Table - the surface of a groundwater body at which the water pressure equals atmospheric pressure. Earth material below the groundwater table is saturated with water.

Yield (Flood Flow) - peak flow divided by drainage area

Appendix C: Abbreviations

CN	Runoff Curve Number
cfs	cubic feet per second
EPA	United States Environmental Protection Agency
GIS	Geographic Information Systems
HSU	MDEQ’s Hydrologic Studies Unit
LID	Low Impact Development
LWMD	MDEQ’s Land and Water Management Division
MDEQ	Michigan Department of Environmental Quality
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service